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ABSTRACT

The objective of this program was to develop candidate pilot performance measures for five undergraduate pilot training (UPT) contact training maneuvers flown in the T-37B aircraft. The work included development and application of a method of analyzing operator performance tasks for purposes of identifying candidate measures. This resulted in sectoring of each T-37B maneuver into functional segments, wherein the dominant measurement variables are consistent, and task segments, wherein the relationships among the dominant measurement variables are consistent. Several types of measures were then defined which, collectively, satisfy measurement needs over all task segments. Specific candidate measurement formulae were developed for each segment in accordance with the analysis results. Computer programs (FORTRAN IV) were developed and implemented to: (1) smooth, printout, and plot data recorded on-board a T-37B aircraft; (2) automatically detect task segment boundaries; (3) compute criterion functions from skilled performer's data; (4) compute measures specified at run-time by the user; and (5) perform and print results of several empirical validation tests of the candidate measures for subsequent researcher analysis. (Author)

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AIR FORCE

HUMAN RESOURCES

CANDIDATE T-37 PILOT PERFORMANCE MEASURES FOR FIVE CONTACT MANEUVERS

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Advanced Systems Division

Approved for publication.

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The objective of this program was to develop candidate pilot performance measures for five undergraduate pilot training (UPT) contact training maneuvers flown in the T-37B aircraft. The work included development and application of a method of analyzing operator performance tasks for purposes of identifying candidate measures. This resulted in sectoring of each T-37B maneuver into functional segments, wherein the dominant measurement variables are consistent, and task segments, wherein the relationships among the dominant measurement variables are consistent. Several types of measures were then defined which, collectively, satisfy measurement needs over all task segments. Specific candidate measurement formulae were developed for each segment in accordance with the analysis results. Computer programs (FORTRAN IV) were developed and implemented to. (1) smooth, print out, and

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plot data recorded on-board a T-37B aircraft, (2) automatically detect task segment boundaries; (3) compute criterion functions from skilled performer's data, (4) compute measures specified at run-time by the user, and (5) perform and print results of several empirical validation tests of the candidate measures for subsequent researcher analysis.

SUMMARY

Problem

The problem was to develop candidate pilot performance measures for five undergraduate pilot training (UPT) contact maneuvers flown in the T-37B aircraft (lazy 8, barrel roll, split S, cloverleaf, and landing). Existing methods of pilot performance measurement are largely subjective, have questionnable validity and reliability, and are relatively insensitive to changes in performance except for gross variances. This makes existing methods less than optimal for training applications per se, and of little scientific value for training research (e.g., flight simulator validation studies) where transfer of training must be assessed. This effort was designed to develop improved measurement methods which overcome many of the disadvantages inherent in existing techniques. The methods were intended for evaluation, cross-validation, and application in the advanced simulator for undergraduate pilot training (ASUPT).

Approach

The approach was one of two alternatives pursued in parallel for the above application. It is characterized by researcher development of candidate measures and assurance of their content validity, followed by automated computation of the measures and execution of various empirical validation tests. (The alternative method (Connelly et al., 1974) involves computer generation of candidate measures from a postulated inclusive family thereof, and execution of empirical validation tests, followed by researcher analysis of results and assurance of the measures' content validity.) The first step of the approach was to analyze each maneuver using a hybrid version of function and task analyses specifically tailored to the identification of candidate measures. Then several types of measures were defined which, collectively, support performance assessment over all maneuver segments. Next, specific measurement formulae were developed for each segment in accordance with the results of the analysis. This included the development of alternative techniques for combining measures over segments and maneuvers. Finally, software was developed to compute measures, from data recorded on a T-37B aircraft, and execute empirical validation tests.

Results

Each maneuver was analyzed and sectored into function and task segments. The function segments identify portions of the maneuver wherein the set of dominant measurement variables is consistent. This identifies sections of each maneuver in which the pilot's primary control functions involve consistent measurable variables, and dictates the types of measures (continuous and discrete) that are applicable to assessing control performance. The task segments identify portions of each function segment wherein the relationships among dominant measurement variables are consistent. This identifies sections of each maneuver in which the pilots' primary control functions themselves remain consistent, and suggests the specific nature of measures that are applicable to performance assessment within the respective task segments.

Several types of measures were identified which satisfy measurement requirements over all task segments, based on application of the above analysis to five maneuvers. Specific measurement formulae were then developed for each segment, exploiting the measure-types previously identified. Software was developed and implemented on a Sigma 5 computer for accomplishing the following tasks: (1) read and remove noise from raw aircraft data; (2) produce print outs and plots of raw and smoothed data at user-specifiable sampling rates; (3) automatically detect boundaries of task segments; (4) compute criterion (reference) functions from skilled performers' data, employing user-specifiable dependent and independent variables; (5) compute task-segment measures of 6 types, parameters of which are changeable by the user; (6) compute segment and maneuver summary measures using alternative methods under study; (7) print results of maneuver segmentation, criterion function generation, and measure computations; and (8) perform and print results of several empirical validation tests.

Conclusions

A unique and relatively effective technique has been developed and applied for identifying candidate performance measures for continuous operator control tasks. The specific objective of developing such

measures for five T-37 pilot maneuvers has been accomplished. In view of the analysis and derivation techniques employed, the candidate T-37 measures possess content validity and are fairly comprehensive.

The segmentation of the maneuvers and development of methods for automatically detecting the segment boundaries provides an important and necessary adjunct to an envisioned measurement system. It is not an especially novel idea, but its criticality has been under emphasized in the past, and it has not been previously developed and applied to the extent accomplished in this study. Two of the maneuvers examined (cloverleaf and approach and landing) are characterized by more than one continuous function segment, within which are numerous differing task segments, each dictating the application of unique measures The other three maneuvers, are largely characterized by a single continuous function segment. However, there are still differing task segments within each function segment, and the initial portions of all maneuvers are characterized by discrete function segments that differ grossly in measurement requirements from their continuous counterparts. In view of this type of analysis as applied to the five maneuvers, it is easy to see why attempts to apply a single continuous measure over an entire control task (or over inappropriate portions thereof) might expectedly result in erroneous deductions about the invalidity of the (valid) measure.

Finally, the software that has been developed and implemented is unique in both capability and flexibility. Inputs to the programs consist of raw performance data and user-specified measures for the various task segments of each maneuver. Outputs consist of the values of computed measures, results of several validation tests that are appropriately computer-implemented, and several summary measures computed using alternative techniques under study. The user can interact with the software effectively in pursuit of an analytic, iterative approach to the development and validation of operator performance measures.

The original objectives of this program included its extension through and including a criterion-related validation phase. It is unfortunate that these objectives could not be fully realized due to non-technical problems that interfered with, and ultimately prevented, the collection of required T-37 data and completion of this phase of the program. Despite this, it is hoped that the work reported here will benefit other researchers investigating similar areas by providing some additional tools and ideas and demonstrating their application, at least in part, to an exemplary measurement problem.

PREFACE

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory (AFSC), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Research was conducted by Quest Research Corporation, McLean, Virginia under Contract F33615-72-C-2028. The work is in support of Project 6114, Simulation Techniques for Aerospace Crew Training, with Mr. Carl F. McNulty serving as Project Scientist.

Quest's principal investigator was Mr. E. M. Connelly. Mr. Francis J. Bourne was Chief Programmer. Mr. Duane A. Burchick completed the work on function and task segmentation. Mrs. Diane G. Loental, Messrs. Joseph S. Migliaccio, James J. Kuhns, Richard D. Taylor and Donald G. Gausvik contributed significantly to the analysis and documentation work on the program. Mrs. Joanne C. Oliver produced the majority of the art work and typed the entire manuscript.

Miss Patricia A. Knoop was Project Engineer for the Air Force and participated in the program in an active, significant manner. The work performed by Mr. Steve Hogue, formerly of the Advanced Systems Division, is gratefully acknowledged. Mr. Hogue developed software techniques required for removing noise from the raw aircraft data.

The authors thank the personnel of the Resources and Instrumentation Branch, Advanced Systems Division, for their support during the preliminary data collection and software implementation phases of this effort. This branch operates the Simulation and Training Advanced Research System (STARS) on which the developed software was debugged and implemented. In particular, the authors thank Mr. Robert Cameron, Mr. William Schelker, and Mr. Robert Roettele for their support of this effort.

Finally, the authors sincerely thank Mr. William Welde of the Personnel and Training Requirement Branch, Advanced Systems Division, for his dedicated and capable management of the aircraft instrumentation and data collection effort designed in part to support this program. His efforts have resulted in a reliable, first-of-its-kind technique for objective in-flight data acquisition in Air Force undergraduate pilot training (UPT).

This report documents research work performed from July 1972 through August 1974.

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CANDIDATE T-37 PILOT PERFORMANCE MEASURES FOR FIVE CONTACT MANEUVERS

I. INTRODUCTION

The purpose of this study was to develop candidate T-37 pilot performance measures for five maneuvers taught in the Air Force undergraduate pilot training (UPT) program. In addition, the study included development of software for computing the candidate measures from performance data recorded on a T-37B aircraft, and performing validation tests. This report documents the approach, the maneuver analyses, the derived candidate measures, and an overview of the implemented computational techniques.

Existing methods of pilot performance measurement are largely subjective and have questionable validity and reliability. This makes them less than optimal for training applications in general, and of little scientific value for simulator training research, where transfer of training must be assessed. This effort was designed to levelop improved measurement methods which overcome many of the disadvantages inherent in existing techniques. The specific goal of developing objective measures of T-37 pilot performance emanated from a requirement for a comprehensive simulator training reasearch capability for effective use of the advanced simulator for undergraduate pilot training (ASUPT).

The research effort, as originally designed, included the development of candidate measures based on their content validity, and the conduct of criterion-related validation studies using student data to be recorded on a T-37 aircraft. Nontechnical problems prevented the required data collection, however, and the study had to be confined to the development of candidate measures, as reported here.

II. APPROACH

There are two basic alternative approaches to deriving candidate measures for a given operator performance task. The approaches differ primarily in. (1) the order in which various types of measure-validity are assured and/or tested, and (2) the loads placed on man versus computer as a result of research task allocations.

Validation tests can be grouped into two fundamental classes, the major distinction being whether or not they are criterion-related. It is also useful, from an operational standpoint, to consider validation tests from the view point of whether or not they can be conducted using a digital computer. For example, it is extremely expedient to automate tests of concurrent validity, where candidate measures are examined on a comparative basis with other independently derived measures of performance. On the other hand, it would be quite difficult to automate tests of content validity, where the aspects of performance assessed by the candidate measures are compared with the behavioral objectives underlying the performance tasks, as evidenced (usually) by task analyses and stated performance objectives.

The research jobs associated with deriving candidate measures include. (1) selecting the specific measures to be explored, (2) assuring their content validity, and (3) testing them empirically for other types of validity (e.g., concurrent). The first job can be performed by man or computer. The second is most efficiently performed by man, since it requires cognitive processing of diverse (often unquantifiable) information. The third is most efficiently performed by a computer, since it requires standardized processing of large quantities of data.

The two approaches mentioned in the opening paragraph are, respectively, to. (1) assign the computer the jobs of generating feasible candidate measures and performing empirical validation tests, followed by manual analysis of results and assurance of the measures' content validity, or (2) assign man the jobs of selecting feasible candidate measures and assuring their content validity, followed by computer tests of the measures for various types of empirical validity. The first approach (Connelly, Bourne, Loental, & Knoop, 1974) places the greatest research load on the computer, and has the advantages of assuring examination of a broad spectrum of measures and of being universally applicable across diverse performance tasks. It is based on a relatively new and unexploited technique of measurement research, however, and is in an exploratory stage of development. The second approach places the greatest research load on the man, and has the major advantages of traditionality and apparent simplicity. It is subject to limitations primarily on

the number and types of measures (from the set of all valid measures) that can be identified and explored, as constrained by the ingenuity and available time of the researcher and the number of measurement problems to be addressed.

This latter approach is the topic of the present report. It was pursued in parallel with the alternative approach for developing measures of performance on 5 UPT maneuvers. lazy 8, barrel roll, split S, approach and landing, and cloverleaf.

III. ANALYSIS OF UPT MANEUVERS

General

This section documents the rationale and methods used for the analysis of the five UPT training maneuvers. The maneuver analysis includes segmentation of maneuvers, identification of pilot skills for each segment, and identification of candidate measures of performance for each segment. While the method was developed for analysis of five specific maneuvers, it is a general one that can be applied to other operator performance tasks.

In addition to a description of the methodology, a list of definitions of critical terms is presented. These terms are in common use in human engineering and many other fields but may have different meanings depending on one's indoctrination. They are defined to reduce ambiguity. The terminology is generally derived from (Meister, 1971, Miller, 1955, Morgan, 1963, Woodsen & Conover, 1970).

Definitions of Critical Terms

A *task* is one or more activities performed by a single human operator to accomplish a specified objective.

A *discrete task* is an all-or nothing task in response to a given signal.

A *continuous task* is continuously performed activity based upon feedback.

A *critical discrimination* is a perceptual process to ascertain a particular variable value to within a specified tolerance. An entire maneuver can be considered as a set of tasks bounded by critical discriminations. These discriminations form the base knowledge for a decision to continue, to initiate an error compensation, or to abort a maneuver.

A *control function* is one of the operational requirements necessary to achieve a portion of the man-machine total output. For example, one control function could be control of pitch necessary to achieve a climbing turn in a Lazy 8 maneuver.

The *set of dominant control functions* are those control functions without which it is impossible to achieve the intended portion of the maneuver.

Subordinate control functions are those used to assist in the efficient performance of a maneuver but which are not essential.

Reference variables are those aircraft flight variables which are used to define the criterion maneuver's trajectory.

Dominant measurement variables are those flight variables which are highly correlated with the control functions which are important to proficiency measurement.

A *function segment* is that portion of a maneuver in which the set of dominant measurement variables is consistent. These segments are classified in two groups, locus segments in which the dominant measurement variables are continuous, and sequence segments in which the dominant measurement variables relate discrete events to a continuously changing variable.

A *task segment* is that portion of a function segment in which the relationship among dominant measurement variables is consistent. A task segment is bounded by critical discriminations. Task segments are the basic measurement segments of that maneuver.

A *skill* is the ability to use knowledge to perform manual operations in the achievement of a specific task objective in a manner which provides for the elimination of irrelevant action and erroneous response. This conceptualization exists only in conjunction with an individual task and is reflected in the quality with which this task is performed.

An *event* is an activity within the total event sequence.

An *event sequence* is a connected series of specified activities occurring in time or in some other continuously changing variable.

Methodology

Methodology Rationale. The objective in the selection of an analytical methodology is the development of pilot proficiency measures. The process used to derive candidate pilot proficiency measures is a hybrid version of a function and task analysis. Normally, a function analysis is used to consider various configurations and allotments of functions between the man and the machine with the objective being the selection of an optimum design. A task analysis is used to investigate performed tasks in order to ascertain those actions which should be appropriated to the equipment and those to be assigned to the human operator in order to achieve overall system efficiency. Since a system design or function allotment is not required here, the function and task analysis used can be simplified.

One basis for the systematic analysis of UPT maneuvers in order to establish pilot proficiency measures is the categorization of human error. In Meister (1971), human error is categorized into three types:

1. Failure to perform a required action; that is, an error of omission.
2. Performance of the mission in an incorrect manner; that is, an error of commission.
3. Performance out of a sequence or at an incorrect time.

Function and task analysis can be used to ascertain these classes of errors, their causes, and their cause/effect relationships. However in training and evaluation, one cannot be constrained by limiting definitions of human error and by analytical approaches tailored to equipment design and development. Recognizing the potentiality of such tools, accepting their limitations, and using such knowledge to develop new tools provides an effective analytical approach. This has been accomplished in the analytical methodology described here.

Historically, maneuvers were developed to train student pilots for combat so that when the aircraft man-machine system is pushed to its capabilities, the pilot has an adequate recovery reaction, derived from a matrix of possible alternatives. The learning task for the neophyte pilot is one of acquiring new maneuver responses The advanced pilot learning task is in the selection and utilization of these responses in such a way as to fulfill a mission objective. Combat skills require a high proficiency in response selection as well as response (performance). Therefore, pilot skill evaluation tools require techniques which allow gathering of information in both areas.

In each of the five UPT maneuvers considered here, the importance of task selectivity is magnified during pilot generated error compensation tasks. One approach used in performance measurement is assessment of a simple difference between the achieved path and the reference path. Thus, when a pilot commits a flight control error this measure continues to penalize him until he recovers. This is in spite of the fact that he may be using correct recovery techniques. Such an approach eliminates measure sensitivity to the skills involved in the recovery tasks performed by the pilot. The freedom of response selection in such tasks is greatly increased over the reference maneuver task, indicating a requirement to develop a high skill level in selection of error recoveries. Therefore, the analytical tools required for this maneuver analysis should include an evaluation of pilot recovery tasks.

Steps Employed in the Development of Pilot Proficiency Measurements. The approach starts with the gathering *(data collection)* and study of basic background information including, but not limited to, aircraft dynamics and maneuver data. Primary data sources included maneuver analyses (Baum, Smith, & Goebel, 1973) prepared with the assistance and active participation of Hq Air Training Command (ATC) officials and current T-37B instructor pilots. Supplementing these basic analyses were ATC flight manuals and technical orders for the T-37B, and maneuver training films used in the academic portion of UPT (see bibliography. Finally, plots of real data recorded on a T-37B aircraft during performance of the maneuvers were used to obtain realistic estimates of ranges, tolerances, and criteria in instances where other data sources produced conflicting or otherwise ambiguous information. (The plots were produced during a previous study to establish the feasibility of automated T-37 performance measurement (Knoop & Welde, 1973)).

The initial review of these data provided the investigating team an excellent general understanding of the performance objectives of each maneuver. In-depth reviews of the data, during the subsequent work on function and task segmentation and identification of candidate measures, assured that maximum use was made of all existing information and included cross-checks between the various data sources.

The following five steps (*function and task segmentation*) are performed uniquely for each maneuver and are implemented in Section VII. The first step is to identify the pilot performance tasks required for each maneuver. This provides a sequential list of all the tasks including control, perceptual, and other required for the performance of the maneuvers.

The second step is to develop time charts for the delineated maneuver tasks for each maneuver. Such a chart indicates the appropriate time domain for each task, the sequence of occurrence, and the appropriate overlapping of task domains. The chart includes control tasks, perceptual tasks, and critical discriminations.

The third step is to determine the control functions required for each task of each maneuver. Emphasis is placed on identification of dominant control functions. The determination of these dominant control functions necessitates the observation of their time relationships. This directly leads into step four which is to identify the maneuver function segments.

Step five is to establish the task segments. This segmentation process follows the function segmentation due to the prerequisite of establishing the appropriate operational requirements for the accomplishment of these specific tasks.

The final three steps (*proficiency measure development*) are implemented in Sections VII and VIII of this report and are as follows:

1. Establish flight error measurement rationale,
2. Develop candidate proficiency measures for each task segment, and
3. Develop candidate methods of combining proficiency measures.

IV. FUNCTION AND TASK SEGMENTATION OF UPT MANEUVERS

General

The analysis techniques discussed in the previous sections were applied to the five UPT maneuvers to identify the measure variables and measurement rationale required to specify candidate pilot proficiency measures. The procedure employed was as follows. (1) Identify pilot performed tasks for each maneuver, (2) Develop time charts for the pilot tasks, (3) Determine control functions required for each task, (4) Identify function segments, and (5) Establish task segments. Logic employed in the methodology for the selection of the measurement variables is shown in Figure 1. For each task in a maneuver, the associated control functions are matched against the measurable flight variables to determine which of these variables are highly correlated with those control functions. The result of this comparison is the identification of candidate measure variables. The nature of the dominant control functions and associated measure variables is examined so that candidate measure operations and methods of combining measures can be devised.

Lazy 8

Table 1 lists the various tasks which must be completed in order to perform a lazy 8 maneuver. These tasks are organized into appropriate function segments and task segments. The first function segment is the "initial" segment in which the establishment of the pre-maneuver flight attitude is attained. There are continuous tasks involved in these initial function segments, however, this does not warrant the treatment of these initial segments as locus segments due to the nature of their discrete outputs. In lieu of this, the initial segment is treated as a sequence segment which relates events in time. As an example of a continuous task being treated as a discrete event, consider the attainment of an airspeed of 215 knots. To do such, a pilot must consistently monitor his airspeed indicator, appropriately adjust the throttle, and either wait for the thrust to boost the airspeed to the desired level or pitch down in order to attain the required velocity. In such a task the primary importance is on the attainment of the required airspeed and less importance is placed on the method of airspeed attainment.

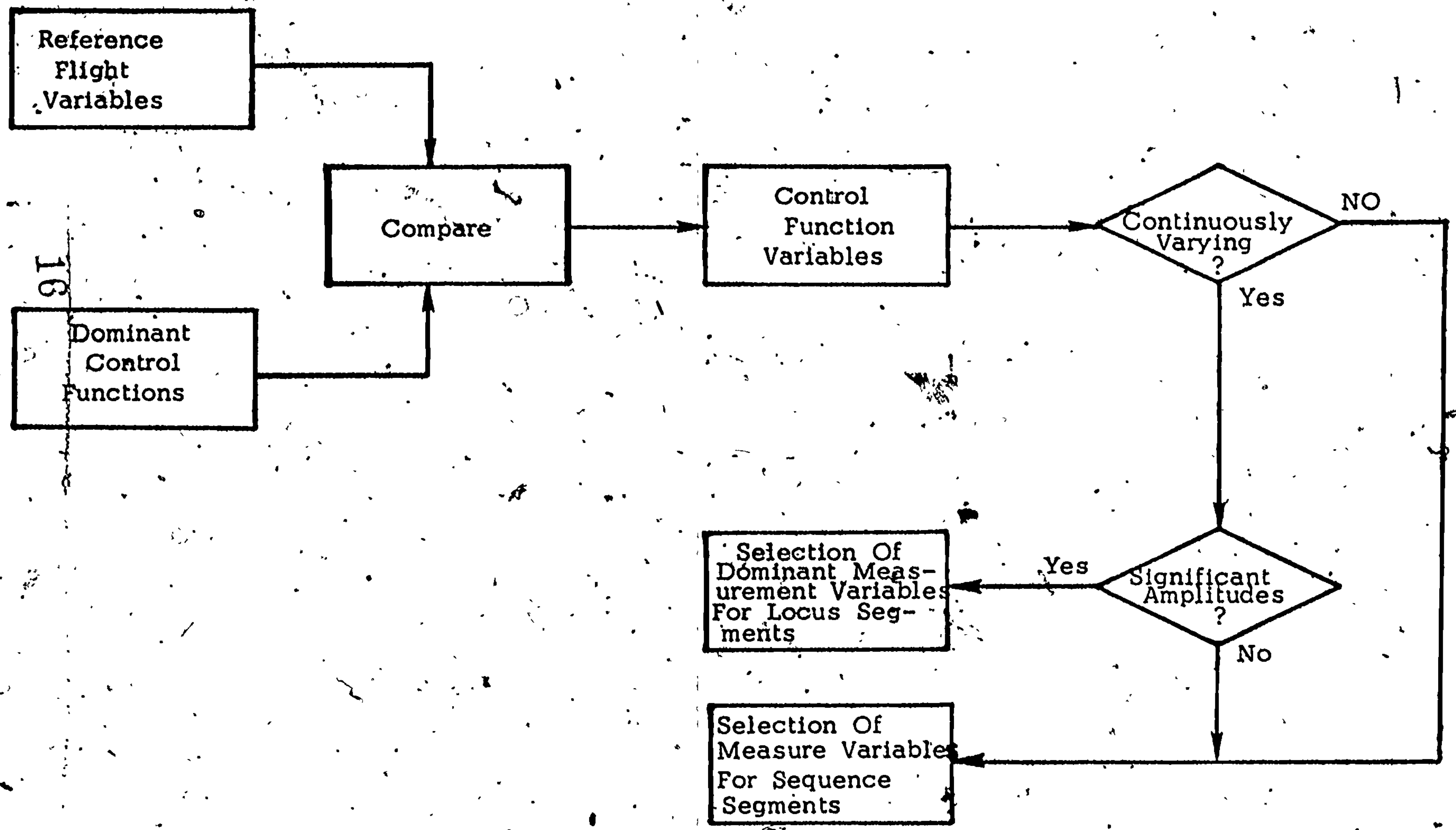


Figure 1. **Measurement variable selection logic.**

Table 1. Lazy 8 Tasks

Function Segment Initial

Task Segment: Initial

1. Establish level flight at 8,000 feet.
2. Set power at 90% RPM.
3. Attain an airspeed of 215 knots.
4. Visually clear the area.
5. Select a horizon reference point directly off the right wing tip.

Function Segment Lazy 8

Task Segment: First Eighth

6. With the aircraft nose projection on the horizon, form a symmetric eight laying on its side with the horizon as the long axis.
7. Blend aileron, rudder and elevator pressures starting a gradual climbing right turn, continuing to monitor and control the pitch, bank and turn rate so as to attain a maximum pitch attitude with 45° of bank at 45° of turn.
8. Monitor and control the turning rate so as to attain the reference point in the center of the windscreen at 90° of turn.
9. Monitor and control the pitch and turning rates so as to attain a 100 knot maximum loss in airspeed at 90° of turn.
10. Monitor and control the roll so as to attain a 90° bank at the lowest velocity point.
11. Establish and discern the maximum pitch attitude with 45° of bank when the aircraft has turned 45°.

Task Segment: Second Eighth

12. Lower the nose slowly to the horizon and toward the reference point while increasing the bank, continuing to monitor and control the pitch, bank, and turn rate so as to attain a 90° roll, zero pitch and 115 knot velocity when the aircraft has turned 90°.
13. Cross and discern the horizon with a 90° bank with a 100 knot loss in entry airspeed with the reference point in the center of the windscreen at maximum barometric altitude.

Task Segment: Third Eighth

14. Decrease the bank at the same rate as it increased in order to describe the same size curve below the horizon as it did above while continuing to monitor and control pitch, bank and turn rate so as to first attain a minimum pitch with 45° of bank when the aircraft has turned 135°.
15. Monitor and control the turning rate so as to attain the reference point off the left wing tip at 180° of turn.
16. Monitor and control the pitch and turning rate so as to attain 215 knots airspeed at 180° of turn.
17. Monitor and control the roll so as to attain level flight at the highest velocity point.
18. Establish and discern the minimum pitch attitude with 45° of bank when the aircraft has turned 135°.

Task Segment: Fourth Eighth

19. Raise the nose slowly to the horizon continuing the roll out so as to attain level flight at 8,000 feet altitude and 215 knots airspeed when the aircraft has turned 180°.
20. Establish and discern the position of the reference point directly off the left wing tip while at 8,000 feet and 215 knots and at the end of the 180° turn.

Task Segment: Fifth Eighth

21. Immediately begin and control a climbing turn in the direction of the reference point at the same rate, same proportion, but in an opposite rotational direction as in the first turn, continuing to monitor and control the pitch, bank and turn rate so as to attain a maximum pitch attitude with 45° of bank at 45° of turn.

Table 1 *(Continued)*

Function Segment Lazy 8

22. Monitor and control the turning rate so as to attain the reference point in the center of the windscreen at 90° of turn.
23. Monitor and control the pitch and turning rates so as to attain a 100 knot maximum loss in airspeed at 90° of turn.
24. Monitor and control the roll so as to attain a 90° bank at the lowest velocity point.
25. Establish and discern the maximum pitch with 45° of bank when the aircraft has turned 45°.

Task Segment: Sixth Eighth

26. Lower the nose slowly to the horizon and toward the reference point while increasing the bank, continuing to monitor and control the pitch, bank and turn rate so as to attain a 90° roll, zero pitch, and 115 knots velocity when the aircraft has turned 90°.
27. Cross and discern the horizon with a 90° bank with a 100 knot loss in entry airspeed with the reference point in the center of the windscreen at maximum altitude.

Task Segment: Seventh Eighth

28. Decrease the bank at the same rate as it increased in order to describe the same size loop below the horizon as it did above while continuing to monitor and control pitch, bank and turn rate so as to first attain a minimum pitch with 45° of bank when the aircraft has turned 135°.
29. Monitor and control the turning rate so as to attain the reference point off the right wing tip at 180° of turn.
30. Monitor and control the pitch and turning rate so as to attain 215 knots airspeed at 180° of turn.
31. Monitor and control the roll so as to attain level flight at the highest velocity point.
32. Establish and discern the minimum pitch attitude with 45° of bank when the aircraft has turned 135°.

Task Segment: Eighth Eighth

33. Raise the nose slowly to the horizon, continuing the roll out so as to attain level flight at 8,000 feet altitude and 215 knots airspeed when the aircraft has turned 180°.
34. Establish and discern the position of the reference point directly off the right wing tip while at 8,000 feet and 215 knots and 180° turn.

Tasks 4 and 5 of the Lazy 8 initial segment are perceptual tasks and cannot directly be measured from the aircraft flight variables.

The next and dominant function segment of the Lazy 8 maneuver is called the Lazy 8 segment. A consistent set of control functions is dominant throughout the entire Lazy 8 function segment, however, there are eight task segments contained within the Lazy 8 function segment. Each task segment ends with specific critical discriminations of flight variable values. Task 6 is the continuous perception task of forming a horizon projection of an 8 laying on its side. This visualization can be closely approximated by a plot in a pitch and roll space. Tasks 11, 13, 18, 20, 25, 27, 32 and 34 are all critical discrimination tasks marking the ending of a prior task segment.

All of the tasks listed in Table 1 are plotted in their associated time domains in the Lazy 8 time chart (Figure 2). In this time chart, the appropriate task segments which follow sequentially in time are listed at the top. All continuous feedback tasks are indicated by circles with lines extending until their termination point in time. The critical discriminations are drawn as triangles. The tasks have been broken down to their smallest components (segments) which are clearly discerned by the appropriate placements of the critical discriminations. (A higher level of task segmentation is possible. For example, there are four equivalent domains in this task time sequence reflecting similar tasks which could have been used for task segmentation. However, the smallest task components are used for this study.)

With the exception of the initial segment the Lazy 8 maneuver is dominated by roll and pitch. Therefore, the employed measurement variables must directly reflect these two dominant control

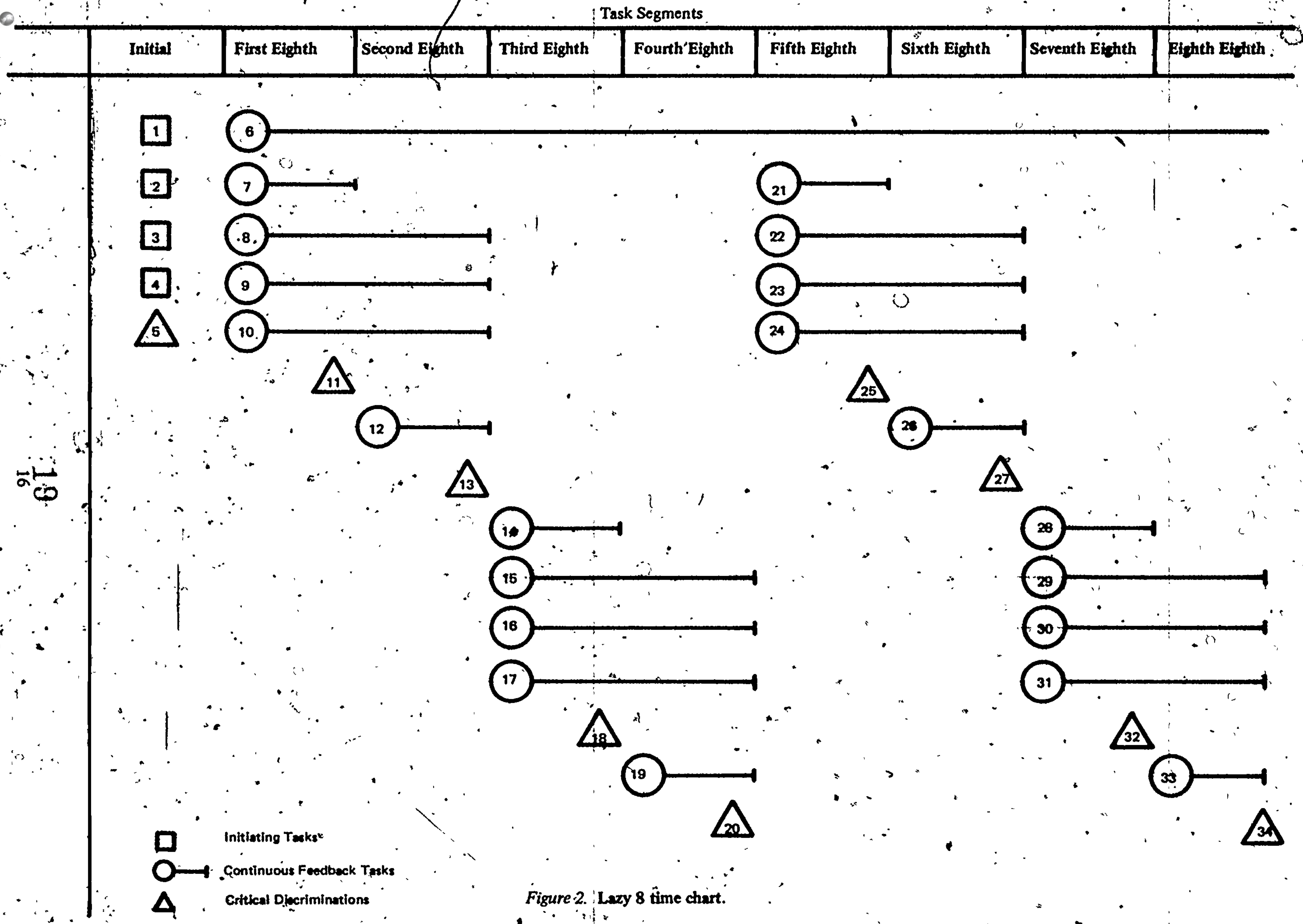


Figure 2. Lazy 8 time chart.

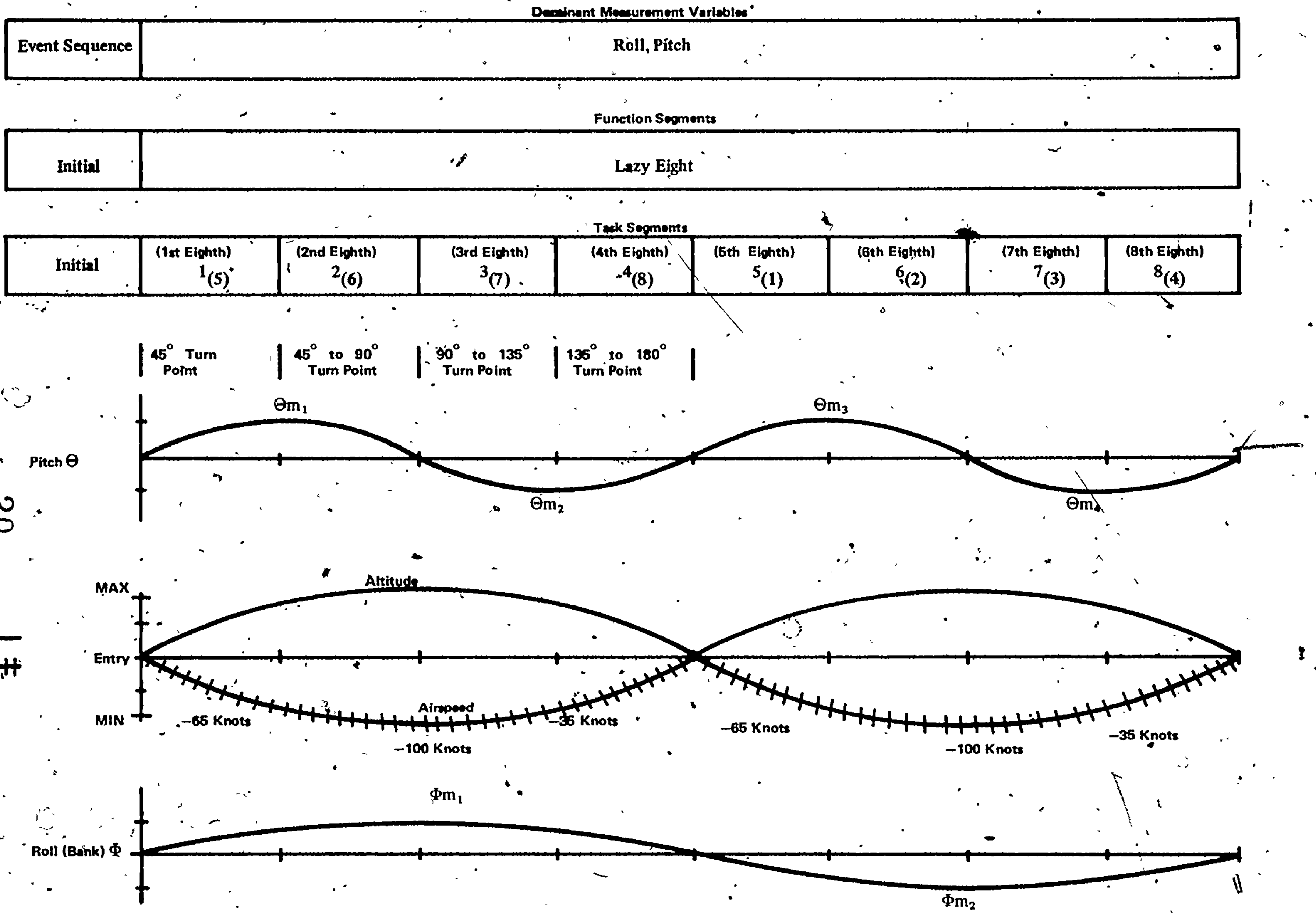


Figure 3. Segmentation of Lazy 8.

functions. Other control functions which influence the system's output are yaw, trim, RPM, the rate of descent and climb, heading, altitude, and airspeed. All of these are factors which the pilot must adequately control. However, roll and pitch maintain their dominance throughout the entire Lazy 8 function segment.

Figure 3 indicates four flight variables (pitch, altitude, airspeed and roll) along with identification of task segmentation and function segmentation. Numbers shown in parentheses adjacent to task segment numbers indicate similar (except for roll) task segments elsewhere in the maneuver. For example, Task Segment 1 is similar to Task Segment 5 except that 5 is accomplished with a negative roll angle. Inspection of the pitch and roll plots show that the critical discrimination tasks are those components where the values of pitch and roll attain maxima, minima, and zero.

Approach and Landing

Table 2 lists the tasks involved in a left-turn landing pattern maneuver. All turns associated with the holding pattern, including the turn into the initial, can be considered as discrete events leading up to the turn entry over the pitch out point. Tasks 5, 8, and 9 are all perception tasks which are not measured directly.

The usual operational method is to evaluate performance of the maneuver up to touchdown. This reflects a training policy which allows a greater number of landing attempts per unit time by landing to touchdown and then immediately taking off ("Touch and go"). However for maneuver analysis the touchdown, the nosedown, and the rollout tasks are considered as part of the landing maneuver.

Figure 4 is the time chart for the normal approach and landing maneuver. The landing is divided into 13 segments. The greatest density of tasks occurs during the descending task segment. The continuous tasks which have dotted lines underneath their straight line extensions are those tasks which involve the monitoring of some continuous variable and the application of a discrete control function. These include trim tasks and ground break tasks. During the downwind segment there are several discrimination tasks which sequentially follow each other. However, these do not constitute individual task segments because except for Task 29, they do not mark the ending of a continuous task.

Table 2. Left Turn Approach and Landing Pattern Tasks

Function Segment: Initial:

Task Segment: Entry

1. Establish level flight at 1,000 feet from holding pattern before entering initial approach.
2. Establish an airspeed of 200 knots.
3. Monitor and control the throttle, pitch and roll so as to maintain a constant airspeed until pitchout is initiated.
4. Monitor and control the pitch so as to maintain a constant altitude until the final turn is initiated.
5. Visually clear the area.

Task Segment: Initial

6. Monitor and control aircraft functions so as to turn onto the initial approach so that the ground track is aligned with the runway centerline.
7. Make the required radio call.
8. Select specific ground references which reflect the rollout (at end of landing see Figure 4) and pitchout points at one half mile from the end of the runway, and 3,000 feet to halfway down the runway, respectively.
9. Visually clear the area of traffic.
10. Establish and discern a ground track rendezvous with the reference pitchout point.

Function Segment: Pitchout:

Task Segment: Pitchout

11. Blend aileron, rudder and elevator pressures establishing a 60° of bank left turn.
12. Monitor and control the turning rate so as to attain a 180° reversal in heading, parallel with the runway.

Table 2 (*Continued*)

Function Segment: Pitchout

13. Retard the throttle to 55% simultaneous with the pitchout.
14. Monitor and control the airspeed to attain a minimum of 120 knots by initiation of the final turn.
15. Monitor and trim pitch and roll so as to relieve undue pressures.
16. Establish and discern a 60° bank.
17. Maintain a 60° banking turn.
18. Establish and discern the appropriate near completion of the turn.
19. Blend aileron, rudder and elevator pressures to rollout completing 180° of turn.
20. Establish and discern a straight and level flight after a 180° turn.

Function Segment: Downwind:

Task Segment: Downwind

21. Select a horizon reference point to aid in runway parallel flight.
22. Monitor and control pitch, roll, and yaw to maintain a flight path parallel to the runway using the reference point as a nose target.
23. Extend the speed brake.
24. Monitor the airspeed and discern the velocity loss to 150 knots.
25. At 150 knots put the gear down.
26. Check that gear is down and locked.
27. Locate the final turn rollout point.
28. Immediately before reaching a position opposite the rollout point, place the flap handle down.
29. Establish and discern a ground track opposite the rollout point.

Function Segment: Final Turn:

Task Segment: Final Turn

30. Immediately opposite the rollout point, blend aileron, rudder and elevator pressures to enter into a 45° descending bank.
31. Monitor and control the descent so as to attain approximately 100 fpm vertical velocity.
32. Monitor and control the descent and turn so as to attain a 700 feet loss in altitude at 180° turn, over the rollout point and aligned with the runway.
33. Monitor and control the airspeed to hold 110 knots.
34. Trim pitch and roll so as to relieve undue pressures.
35. Establish and discern a 45° descending bank.
36. Maintain a 45° descending turn.
37. Make the required radio communication.
38. Establish and discern the appropriate near completion of the turn.
39. Blend aileron, rudder and elevator pressures to rollout, completing 180° turn.
40. Establish and discern a 700 feet loss in altitude at 180° of turn in a level and falling trajectory, aligned with the runway when the ground track rendezvous with the rollout point.

Function Segment: Glide Path:

Task Segment: Final Approach

41. Maintain alignment with the runway.
42. Maintain a smooth constant glide path by controlling throttle and pitch so that the last 300 feet of altitude is traversed when the aircraft reaches the touchdown point.
43. Place the end of the runway (aim point) in the center of the windscreen and maintain it at this position until roundout.
44. Control the throttle to allow the airspeed to decrease to 100 knots.
45. Establish and discern the desired airspeed coincident with a position just in front of the aim point.

Table 2 (*Continued*)

Function Segment: Glide Path:
Task Segment: Roundout
46. Immediately before the aim point is reached apply back pitch pressure to hold the aircraft just off the runway.
47. Gradually reduce the power to idle and decrease the airspeed to 75 knots.
48. Establish and discern aircraft holding position just off the runway.
Task Segment: Touchdown
49. Control the pitch to smoothly touchdown the rear wheels.
50. Establish and discern rear wheel touchdown.
51. Control the pitch to smoothly lower the nose wheel to the runway.
52. Establish and discern nose wheel touchdown.
53. Retract the speed brake.
54. Check rudder pedals to neutral.
55. Engage nose wheel steering.
56. Control and monitor nose wheel steering.
57. Apply brake pressure as required to slow to taxiing speed.

The major control functions fulfilled by the pilot for the normal approach and landing pattern are roll, pitch, airspeed, altitude, and ground track. Of these, airspeed is a function of RPM and other flight control functions. Perceptive process functions monitor and analyze the corresponding flight variables which reflect these control functions and determine their impact upon airspeed. Airspeed, therefore, becomes the focus of functions, and is dominant for certain segments. A similar rationale also applies for the altitude control function.

Minor control functions required during a normal approach and landing maneuver are trim, rate of descent, nose wheel steering, wheel brakes, RPM, yaw and heading. These continuous functions are affected by the application of the discrete control functions of speed brakes, flaps and gears. For the purpose of analysis, the trim and the wheel brakes control function is included in the continuous control functions due to the nature of the continuous monitoring tasks which must be performed in order to utilize these discrete control functions.

The dominant control functions required for the various functional segments are as follows:

1. The initial functional segment has the dominant control functions. airspeed, altitude, and ground track.*

2. The pitchout functional segment has the dominant control functions: roll, pitch, airspeed, altitude, and ground track.*

3. The downwind functional segment has the dominant control functions. pitch, airspeed, altitude, and ground track.*

4. The final turn functional segment has dominant control functions. roll, pitch, airspeed, altitude, and ground track.*

5. The glide path has dominant control functions: pitch, altitude, airspeed, and ground track.*

6. The rollout functional segment has ground track* as its dominant control function.

*Ground track is not measured directly in the aircraft. It may be possible to use heading information in conjunction with an estimate of wind forces and an aircraft model to estimate ground track.

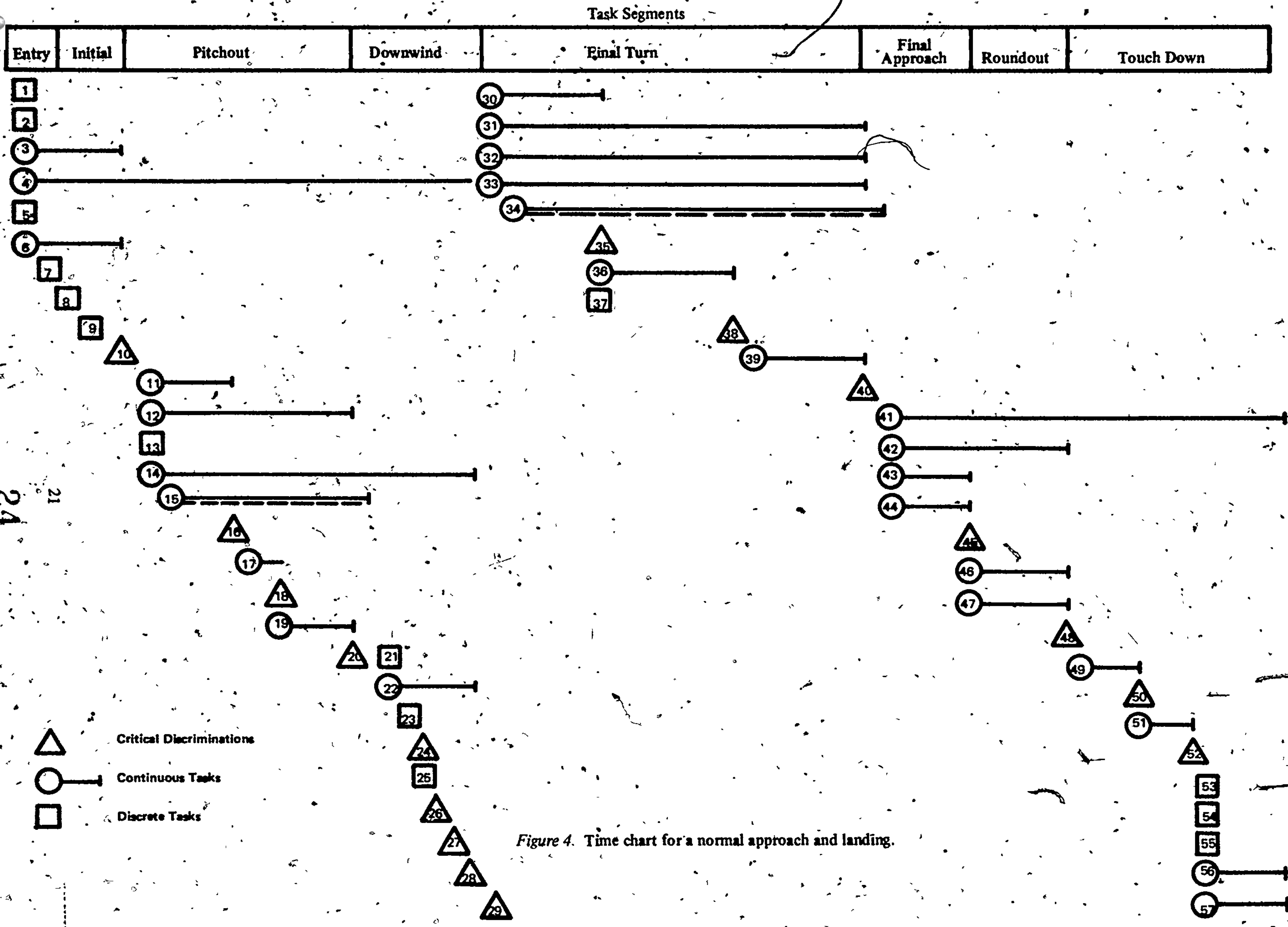


Figure 4. Time chart for a normal approach and landing.

Figure 5 relates various variables and segments for the Normal Landing maneuver in the appropriate time domain. During the initial function segment, the dominant control functions do not reflect variables which maintain significant amplitudes in their variations. Therefore, the initial function segment can be considered as an event sequence, i.e., measured with respect to an end condition tolerance. On the other hand, the pitchout functional segment does maintain significant amplitudes in the variation of their respective flight variables. Therefore, roll and airspeed are candidate measure variables in that segment. Thus, the pitchout functional segment is treated as a locus segment. On the other hand, the downwind functional segment maintains a significant variation of only one dominant control function (airspeed). Therefore, it is useful to consider the downwind as an event sequence which is ordered with respect to airspeed. The final turn maintains significant amplitudes in the variations of control functions roll, pitch, and altitude. In this instance, the rate of change of altitude is a function of the pitch. Therefore, it would be efficient to exclude either the altitude or the pitch from the measurement variables since one of these reflects the other. Since altitude is the net end objective of pitching, the pitch is dropped in favor of the altitude measurement variable. The glide path can include the tasks of roundout, touchdown and nosedown if these tasks can be measured. Pitch is considered as a measurement variable along with altitude and airspeed. As before, altitude rate of change is a function of pitch and other variables, but, glide path errors can be analyzed as an independent variable. Finally, the rollout is analyzed as an event sequence in time.

Barrel Roll

Table 3 lists the tasks involved for the performance of the Barrel Roll maneuver. The Barrel Roll tasks are similar to those of the Lazy 8 maneuver. They both require a perceptual task to form a specified geometric figure with the nose projection upon the horizon. Figure 6 illustrates the Barrel Roll with its task segments time charted. In this case, there are two initiating task segments leading up to the Barrel Roll maneuver segments. These are termed "initial" and "entry." Both segments contain continuous feedback tasks terminating with critical discriminations. Note the overlapping and sharing of the same time space of Tasks 9, 10, 11, 12, 13, and 14.

The Barrel Roll can be divided into two partitions of consistent continuous control function domains. These segments are termed "initial" and the "barrel." The initial includes two task segments (initial and entry), as discussed previously. The reason both segments are considered within the same functional segment is due to the shared objective of entry attitude. This consideration allows the treatment of the initial function segment as an event sequence in time. The initial function segment has dominant control functions: airspeed, altitude and heading. Its minor control functions are yaw, pitch and roll. During the initial segment, the pitch seems to take on the major function role. However, the objective of the pitch down phase of the initial segment is the attainment of a specific airspeed. This attainment of airspeed is so specific that it can therefore be clearly separated from the primary portions of the barrel roll maneuver. The same argument applies for the roll during the entry task segment.

Table 3. **Barrel Roll Tasks**

Function Segment: Initial:

Task Segment: Initial

1. Establish level flight at 8,000 feet.
2. Select a reference point on or near the horizon.
3. Visually clear the area of all aircraft.
4. Set power at 90% RPM.
5. Enter a shallow dive with the nose of the aircraft below the reference point in order to attain an air speed of 230 knots.
6. Establish and discern an airspeed of 230 knots.

Task Segment: Entry

7. Begin a coordinated turn in the opposite direction of the desired roll in order to raise the nose to the horizon at a wings-level attitude in a direction 20° – 30° to the side of the reference point.
8. Establish and discern a level flight in a direction 20° – 30° to the side of the reference point.

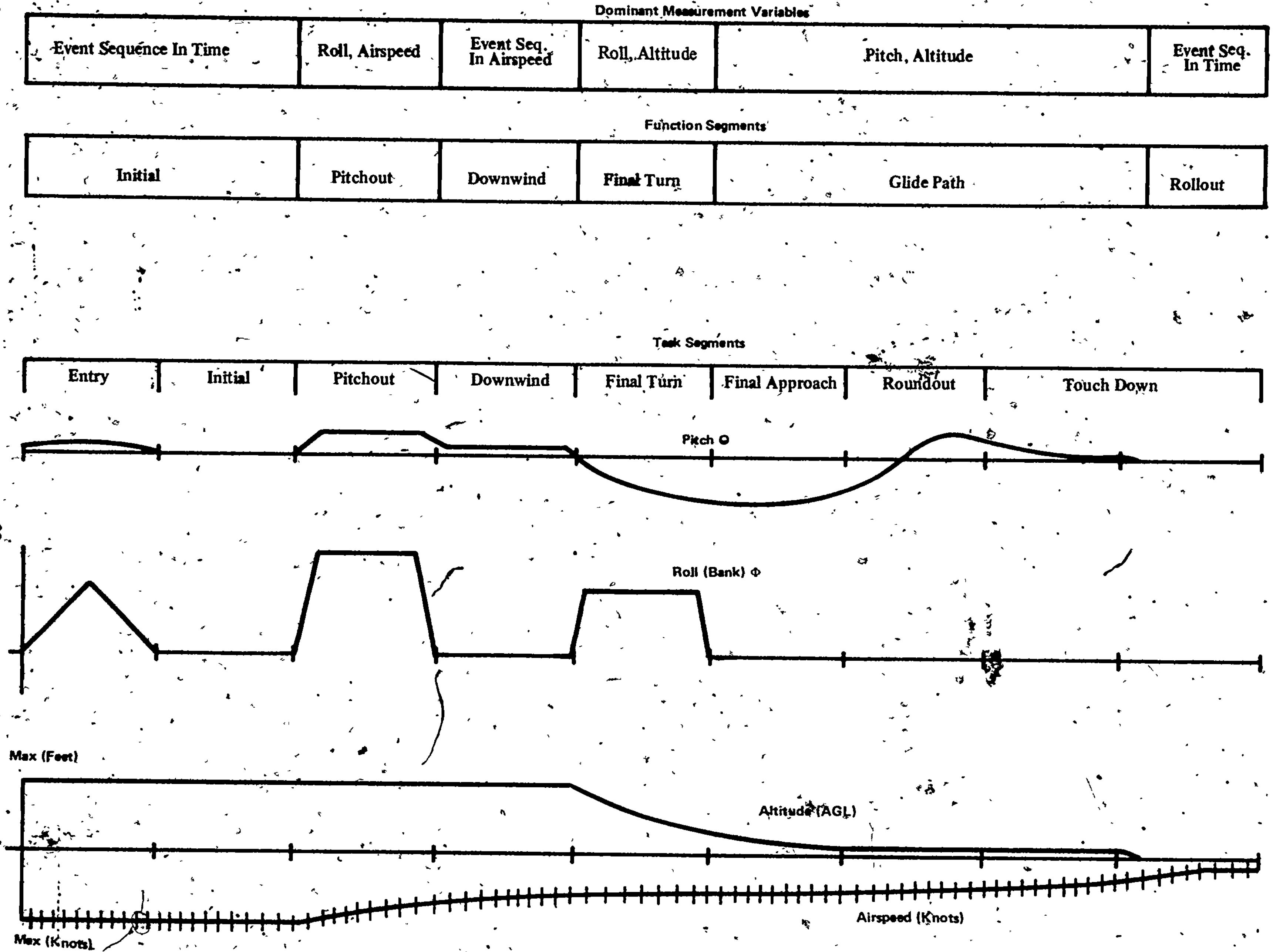


Figure 5. Segmentation of normal landing.

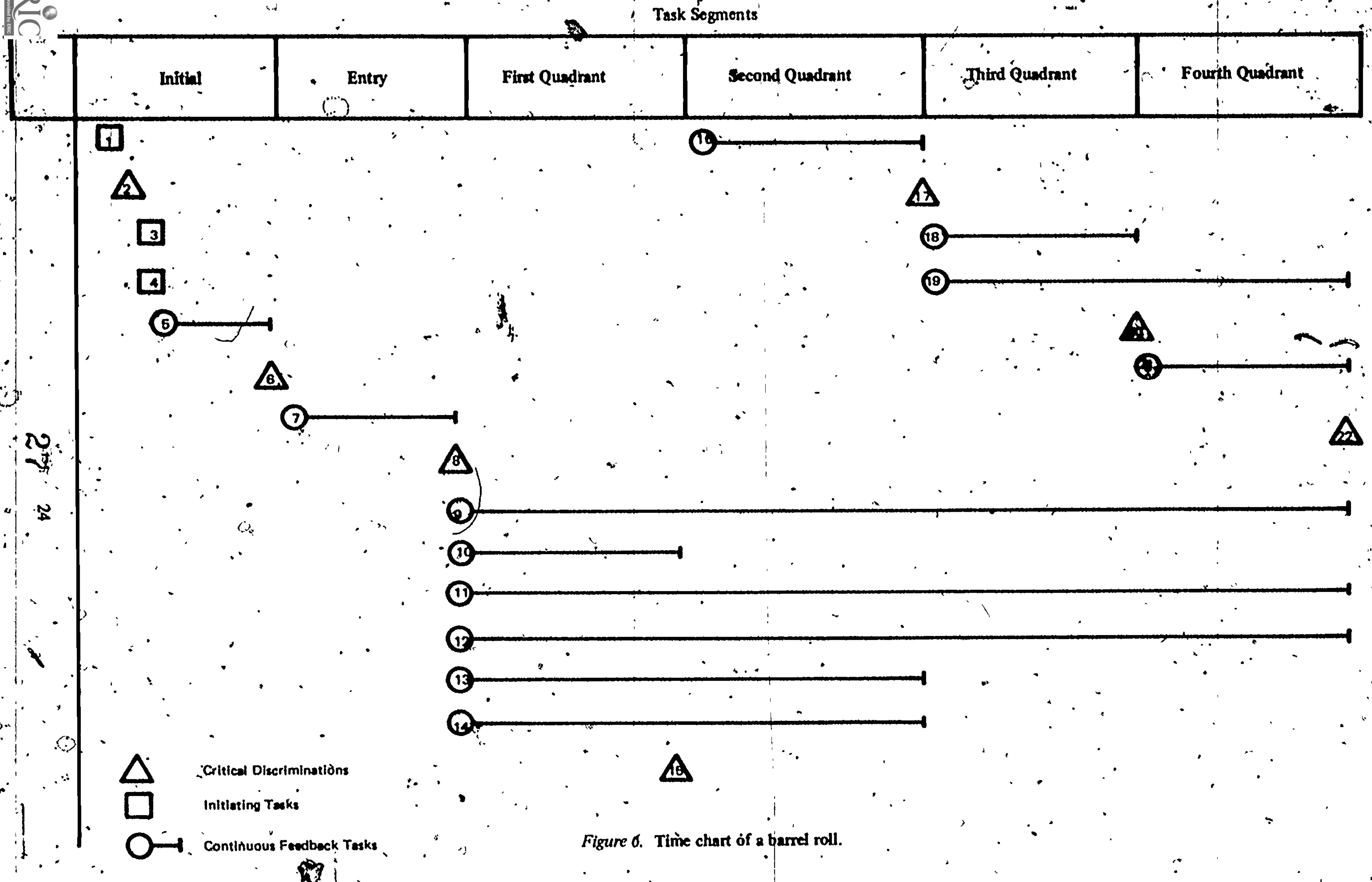


Figure 6. Time chart of a barrel roll.

Table 3 (*Continued*)

Function Segment: Barrel:

Task Segment: First Quadrant

9. Monitor and control the aircraft flight parameters such that the nose of the aircraft describes a circle around the reference point on the horizon.
10 Immediately and smoothly raise the nose while gradually blending in aileron and rudder pressure entering a climbing roll, so that maximum pitch rendezvous with 90° roll.
11. Control ailerons so that a constant rate of roll is maintained throughout the maneuver.
12 Control pitch, roll and yaw such that the angle between the reference point and the nose projection is kept constant throughout the maneuver.
13. Coordinate the controls so that minimum airspeed coincides with inverted flight, not to decrease below inverted stall.
14. Coordinate the controls so that maximum altitude coincides with inverted flight.
15 Establish and discern a maximum pitch equal to the original offset angle when a 90° roll is attained, thus describing one quadrant of the projected circle.

Task Segment: Second Quadrant

16 Relax some of the back pressure while continuing the same rate of roll by blending in more aileron pressure so as to attain a 180° roll at zero pitch with an offset angle equal to the initial but to the opposite side of the reference point, with the minimum airspeed and maximum altitude.
17. Establish and discern a 180° roll at zero pitch with an offset angle equal to the initial but to the opposite side of the reference point, with the minimum airspeed and maximum altitude thus describing the top half of the projected circle.

Task Segment: Third Quadrant

18 Begin applying increasing back pressure while continuing the same rate of roll by decreasing aileron pressure so that the nose of the aircraft describes the third quadrant of the projected circle below the horizon culminating with a maximum negative pitch rendezvous with 270° of roll.
19 Coordinate the controls so that minimum altitude equal to that of the initial low altitude, coincides with level flight.
20 Establish and discern that the maximum negative pitch coincides with 270° of roll, thus describing three-quarters of the completed circle.

Task Segment: Fourth Quadrant

21 Increase back pressure and decrease aileron pressure so as to attain a 360° roll with a zero pitch at an offset angle the same as the initial.
22 Establish and discern a level flight at the original offset angle to the reference point thus describing the completion of the 360° nose projected circle about the reference point.

During the barrel function segment, pitch and roll are the dominant control functions. The minor control functions are yaw, altitude, airspeed and heading.

The dominant control functions are shown as a function of time in Figure 7. Pitch and roll are seen to maintain significant amplitudes in their variation and are continuously variable throughout the entire maneuver. Therefore, the barrel function segment can be considered as a locus segment described by a functional relationship between roll and pitch.

Split S

Table 4 lists the tasks required for the performance of the Split S Maneuver. The Split S is a recovery maneuver from a position of near stall with 90 percent of the engine power. There are 17 tasks involved in the performance of this maneuver. These tasks are divided into 4 task segments. initial, entry, pull through, and exit These task segments are in turn subsets of the two function segments, the initial and the half-loop. The final objective of the initial function segment is to pitch up and roll to inverted so that a pull through

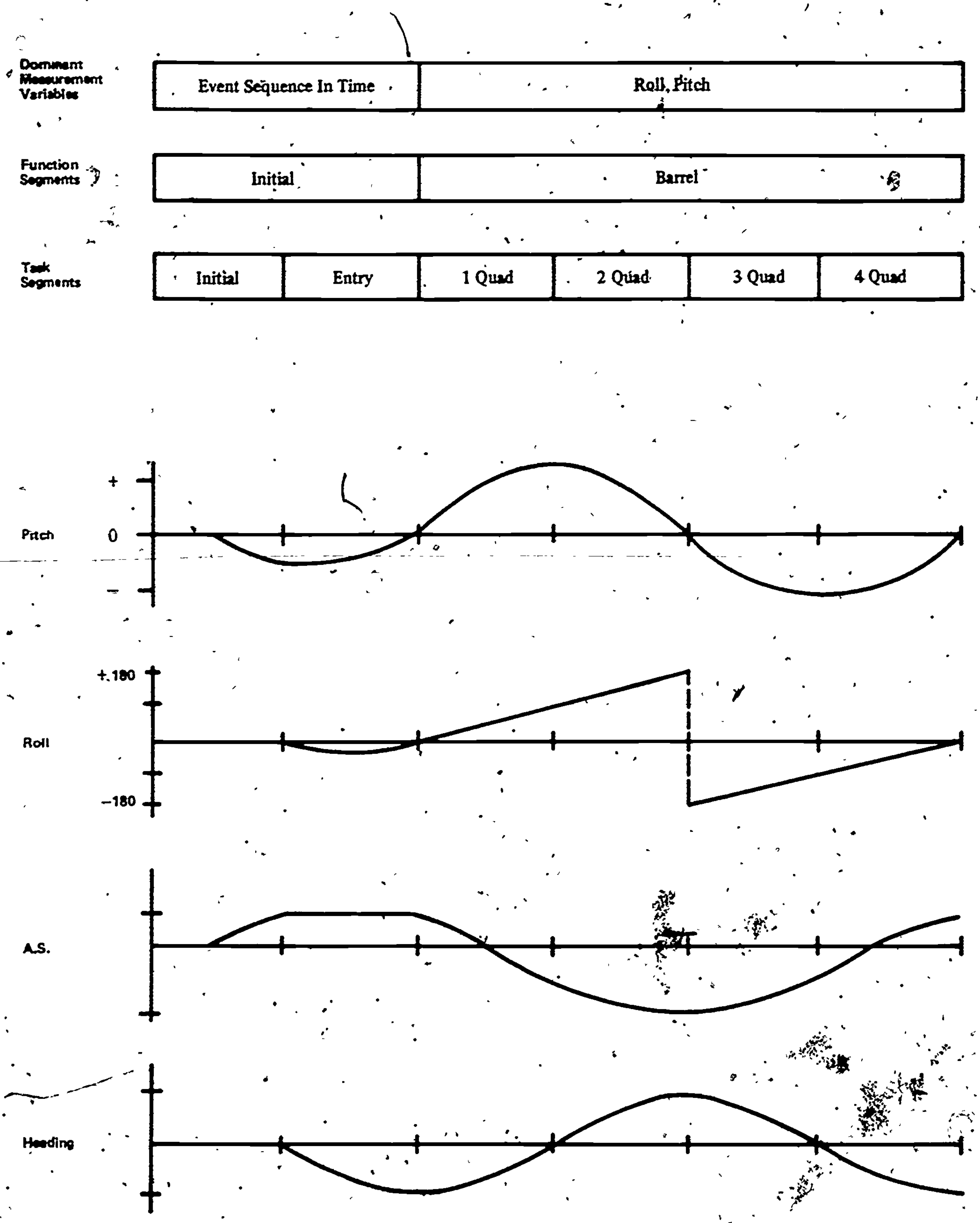


Figure 7. Segmentation of barrel roll.

recovery can be initiated. The time sharing of these tasks is represented in Figure 8. Task difficulties are increased at the entry point as shown by the time sharing of Tasks 10 and 11. This difficulty of sharing time domain between various tasks continues throughout the entire half-loop function segment. Note that the roll to inverted is a continuous feedback task occupying very little time. Its objective is to attain an attitude for pull through execution. Therefore, it is considered as an event in the event sequence of the initial function segment. The same holds true for the pitch up at the start of the climb.

Table 4. Split S Tasks

Function Segment: Initial:

Task Segment: Initial

1 Establish level flight at a sufficient altitude so that the altitude loss incurred in the maneuver does not cause a penetration below 5,000 feet altitude.
2. Set power at 90% RPM.
3. Visually clear the area of all aircraft.
4. Pitch up 25°.
5. Monitor the airspeed to ascertain a decrease to 120 knots.
6. Lower the speed brake if the airspeed is excessive.
7. Establish and discern a 120 knot airspeed.
8. Retract the speed brake if used.
9. Roll the aircraft 180°.

Function Segment: Half Loop

Task Segment: Entry

10. Execute a half-loop to attain a reversal in heading arriving at an erect and level attitude.
11. Slowly apply back pitch pressure bringing the nose of the aircraft through the horizon in order to attain the maximum back pitch pressure possible without stalling.
12. Establish and discern a maximum pitch back pressure without stalling.

Task Segment: Pull Through

13. Monitor and control the acceleration to insure that the 'G' limit is not exceeded through the pull through.
14. Hold a maximum back pitch pressure.
15. Establish and discern the appropriate near completion of the pull through.

Task Segment: Exit

16 Release back pressure as the pull through nears completion to attain level flight in a reversed heading.
17. Establish and discern a reversal in heading at a straight and level attitude.

The continuous control functions altitude, airspeed, pitch, and roll are dominant in the initial function segment.

Minor continuous control functions are yaw and heading. Pitch and acceleration are dominant control functions for the half-loop function segment. The minor functions are altitude, airspeed, and heading. Figure 9 illustrates the dominant measure variables as a function of time. As shown, they further maintain significant amplitudes in their variations and their first time derivatives consistently sustain non-zero values.

Cloverleaf

The Cloverleaf maneuver is broken into component tasks as shown in Table 5. It shows the parallel relationship to the Split S maneuver. As with the other maneuvers, the first function segment establishes the entry attitude for the aircraft. The climb function segment follows the initial and is the entry into the loop portion of the maneuver. Pitching up until 45° pitch angle is attained, the pilot enters into the ascent

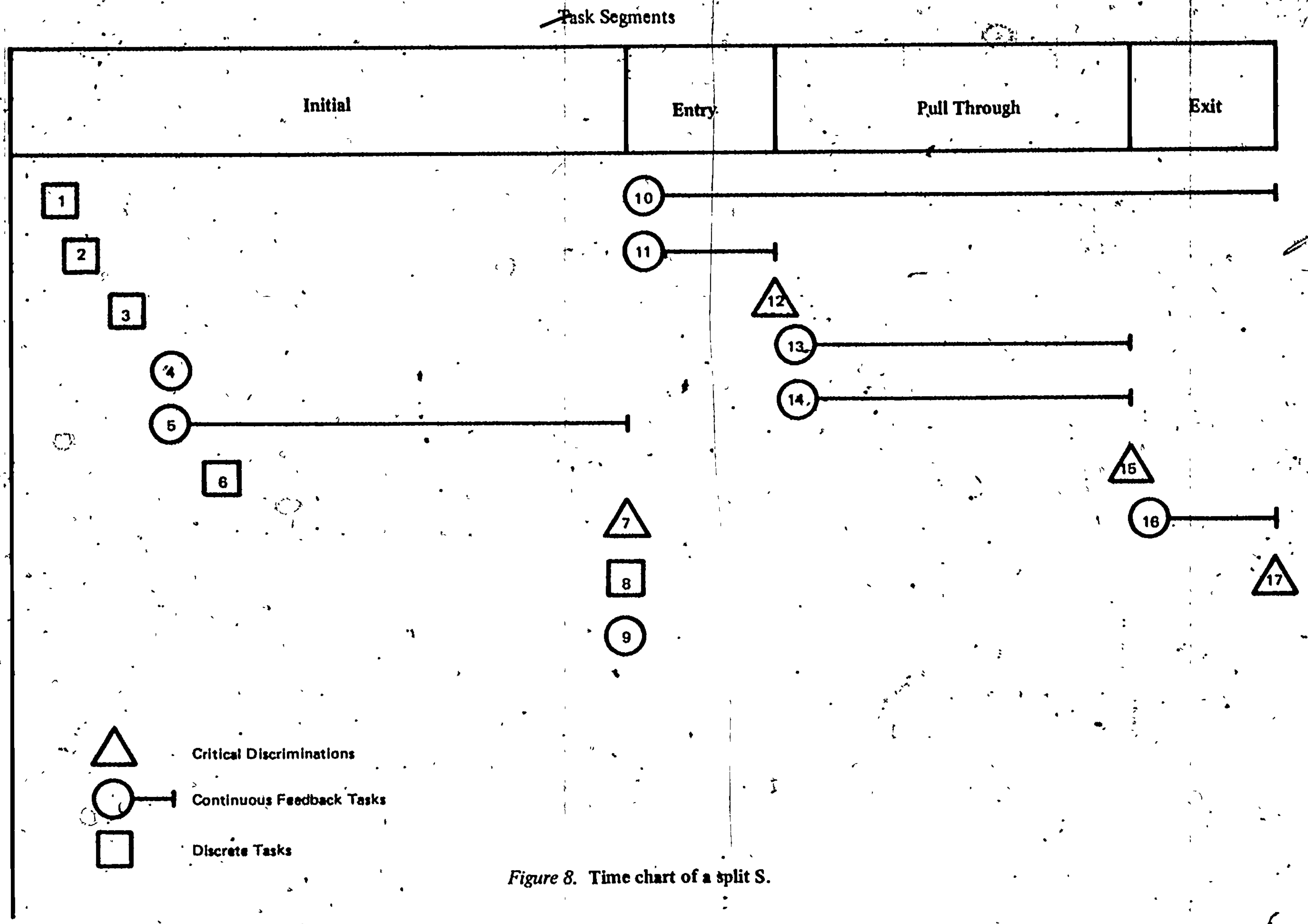


Figure 8. Time chart of a split S.

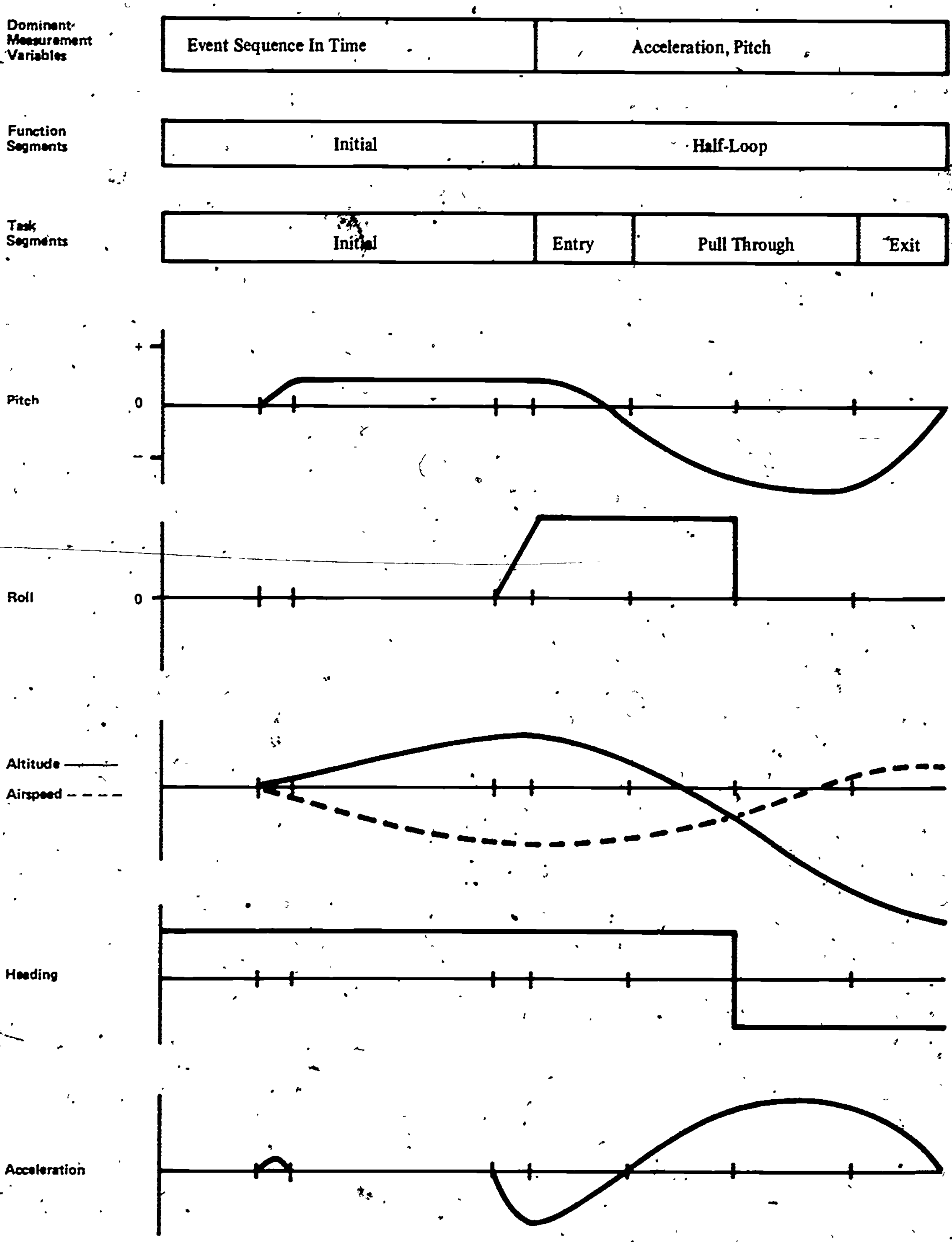


Figure 9. Segmentation of split S.

turn function segment which is the first of the 4 similar loop function segments to be employed. The ascent turn basically accomplishes a roll to inverted along with a 90° change in heading. The half-loop function segment is a pull through similar to that of the Split S maneuver except instead of exiting at a level flight attitude, the pitchout is continued by raising the nose through to another ascent turn functional segment. The repetition of these two functional segments continues until the fourth and final cloverleaf loop is in its half-loop phase. At this point in the maneuver, the pull through is scheduled for termination just before the straight and level attitude is attained. The rate of pitch change is diminished to zero instead of following through with a continued pitch rise. This accomplishes an effective exit from the maneuver at a straight and level attitude.

Table 5. **Cloverleaf Tasks**

Function Segment: Initial:

Task Segment: Initial

1. Establish level flight at 8,000 feet.
2. Set throttle to 95% RPM.
3. Visually clear the area of all aircraft.
4. Select 4 reference points on the horizon. one to the front, one to the rear, and one off of each wing tip.
5. Enter a shallow dive to gain sufficient airspeed so that as the aircraft is returned to level flight, an entry airspeed of 220 knots is attained.
6. Establish and discern a level flight at 220 knots.

Function Segment: Climb:

Task Segment: Pitch Up

7. Perform four equivalent twisted loops, turning 90° from entry heading at 45° of ascent pitch in such a manner as to form two concentric crosses on the ground with the nose projection. The cross tips should terminate at the 4 reference points.
8. Immediately following the 220 knot airspeed attainment, continue smoothly exerting back pitch pressure to maintain a constant rate of pitch in an ascending loop so as to attain a 45° pitch attitude.
9. Coordinate the controls so that minimum airspeed coincides with maximum altitude at inverted flight at the top of the twist loop.
10. Monitor and control the loop turning rate so that level attitude coincides with 90° to the right change in heading at the end of the loop.
11. Establish and discern a 45° pitch attitude with zero roll.

Function Segment: Ascent Turn:

Task Segment: Turn

12. Blend in roll to execute a 90° left ascending turn attaining an inverted attitude directly heading at the left wing reference point at the top of the first loop.
13. Establish and discern a 90° left turn, inverted attitude, maximum altitude and minimum airspeed at the top of the first twisted loop.

Function Segment: Half Loop

Task Segment: Pull Through

14. Execute a loop to attain a reversal in heading, arriving at a 45° pitch with a zero roll.
15. Control the aircraft in such a manner as to point a straight line from the original left wing tip horizon reference point to the right wing reference point with the aircraft nose projection. This line will be perpendicular to the original line of travel.
16. Monitor and control the pitch to insure that the 'G' limit is not exceeded through the pull through and a constant rate of pitch change is maintained.
17. Establish and discern the right reference point in the center of the windscreen at level flight completing one perpendicular line projection and completing one loop.

Table 5 (*Continued*)

Function Segment: Half Loop

Task Segment: Pitch Up 2

18. Coordinate the control so that minimum airspeed coincide with maximum altitude at inverted flight at the top of the twisted loop.
19. Monitor and control the loop turning rate so that level attitude coincides with 90° to the right change in heading at the end of the loop.
20. Establish and discern a 45° pitch attitude with zero roll.

Function Segment: Ascent Turn 2:

Task Segment: Turn 2

21. Blend in roll to execute a 90° left ascending turn attaining an inverted attitude directly heading at the forward reference point at the top of the loop.
22. Establish and discern a 90° left turn, inverted attitude, maximum altitude and minimum airspeed at the top of the second twisted loop.

Function Segment: Half Loop 2:

Task Segment: Pull Through 2

23. Execute a loop to attain a reversal in heading, arriving at a 45° pitch with a zero roll.
24. Control the aircraft in such a manner as to point a straight line from the original forward horizon reference point to the rear reference point with the aircraft nose projection. This line will be parallel to the original line of travel.
25. Monitor and control the pitch to insure that the 'G' limit is not exceeded through the pull through and a constant rate of pitch change is maintained.
26. Establish and discern the rear reference point in the center of the windscreen at level flight completing the parallel line projection, the first ground cross, and the second loop.

Task Segment: Pitch Up 3

27. Coordinate the controls so that minimum airspeed coincides with maximum altitude at inverted flight at the top of the twisted loop.
28. Monitor and control the loop turning rate so that level attitude coincides with 90° to the right change in heading at the end of the loop.
29. Establish and discern a 45° pitch attitude with zero roll.

Function Segment: Ascent Turn 3:

Task Segment: Turn 3

30. Blend in roll to execute a 90° left ascending turn attaining an inverted attitude directly heading at the right reference point at the top of the loop.
31. Establish and discern a 90° left turn, inverted attitude, maximum altitude, and minimum airspeed at the top of the third twisted loop.

Function Segment: Half Loop 3:

Task Segment: Pull Through 3

32. Execute a loop to attain a reversal in heading, arriving at a 45° pitch with a zero roll.
33. Control the aircraft in such a manner as to point a straight line from the original right horizon reference point to the left reference point with the aircraft nose projection. This line will be perpendicular to the original line of travel.
34. Monitor and control the pitch to insure that the 'G' limit is not exceeded through the pull through and a constant rate of pitch change is maintained.
35. Establish and discern the left reference point in the center of the windscreen at level flight completing the perpendicular line projection, the first axis of the second cross, and the third loop.

Table 5 (*Continued*)

Function Segment: Half Loop 3:

Task Segment: Pitch Up 4

36. Coordinate the controls so that minimum airspeed coincides with maximum altitude at inverted flight at the top of the twisted loop.
37. Monitor and control the loop turning rate so that a level attitude coincides with 90° to the right change in heading at the end of the loop.
38. Establish and discern a 45° pitch attitude with zero roll.

Function Segment: Ascent Turn 4:

Task Segment: Turn 4

39. Blend in roll to execute a 90° left ascending turn attaining an inverted attitude directly heading at the rear reference point at the top of the loop.
40. Establish and discern a 90° left turn, inverted attitude, maximum altitude, and minimum airspeed at the top of the fourth twisted loop.

Function Segment: Half Loop 4:

Task Segment: Pull Through 4

41. Execute a loop to attain a reversal in heading, arriving at a zero degree pitch with a zero roll, headed in the original direction.
42. Control the aircraft in such a manner as to point a straight line from the original rear horizon reference point to the forward reference point with the aircraft nose projection. This line will be parallel to the original line of travel.
43. Monitor and control the pitch to insure that the 'G' limit is not exceeded through the pull through and a constant rate of pitch change is maintained.
44. Establish and discern the appropriate near completion of the pull through.

Task Segment: Exit

45. Release back pressure as the pull through nears completion to attain a level flight in the original heading.
46. Establish and discern the forward reference point in the center of the windscreen at level flight heading in the original direction completing the last parallel line projection, the second ground cross and the fourth loop.

The composite tasks involved in the accomplishment of each of the function segments are schematically drawn in Figure 10, the Cloverleaf Time Chart. As shown, the repeated structure in flight tasks begins during the first ascending turn. This in turn is duplicated during the subsequent ascending turns two, three, and four.

The dominant continuous control function utilized during the initial function segment are the functions of airspeed, heading, pitch and altitude. Roll and yaw are of relatively minor importance during this functional segment. During the climb, pitch is the single major control function while heading, altitude and airspeed take on relatively minor importance. Pitch and roll are the dominant continuous control functions for the ascent turns. Heading, altitude, airspeed and yaw are supportive control functions which aid specifically in the discriminatory tasks. Pitch and acceleration control are dominant during the half-loop. The minor functions are heading, altitude, and airspeed. The relationship in time between these dominant control functions is shown in Figure 11, which relates the measurement variables, function segments and various flight parameters for the Cloverleaf maneuver. The initial and climb function segments can be treated as a single event sequence in time. Thus, proficiency for that segment can be measured by a test which determines if variable values are within tolerance limits at the end of the segment.

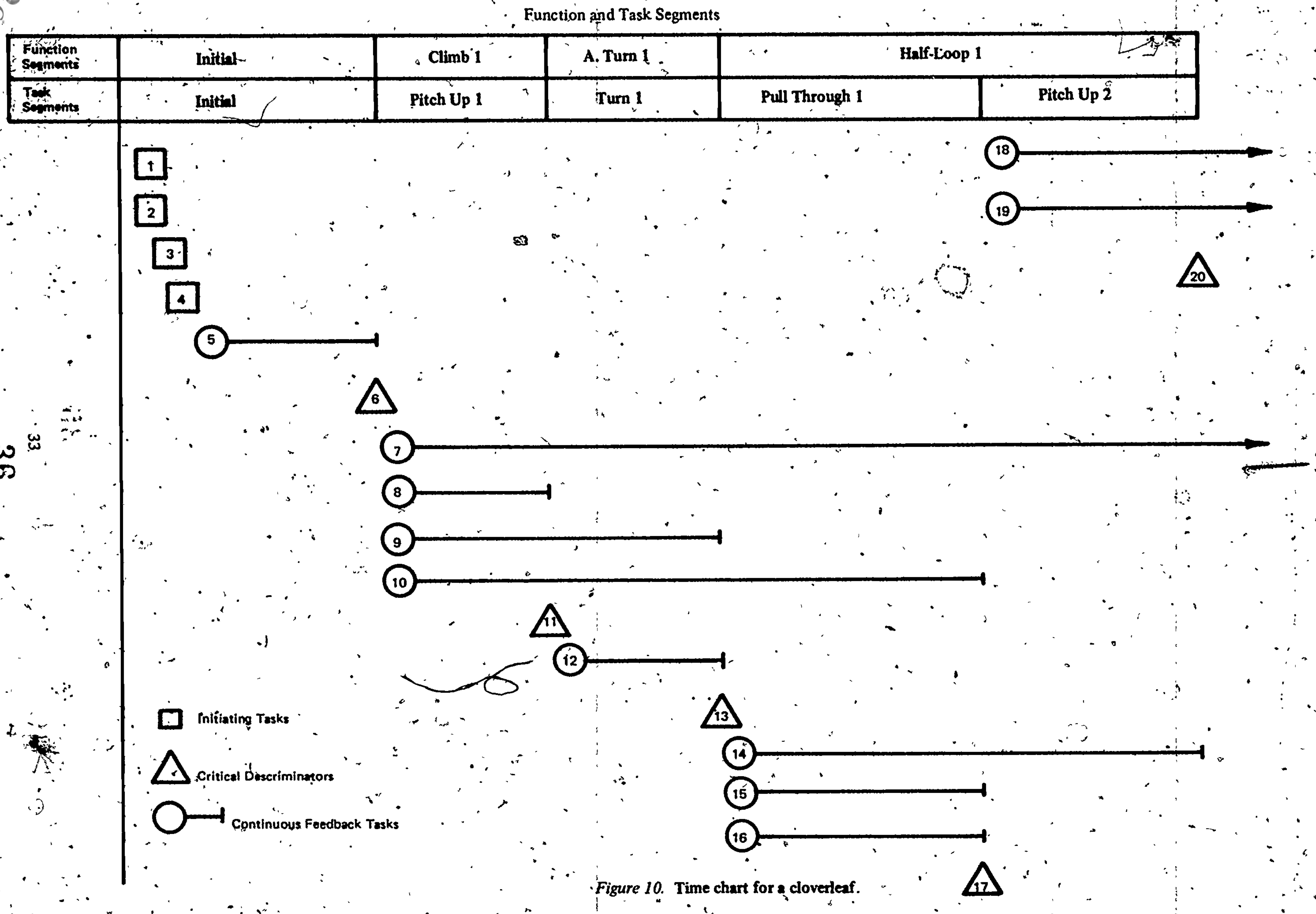


Figure 10. Time chart for a cloverleaf.

Function and Task Segments

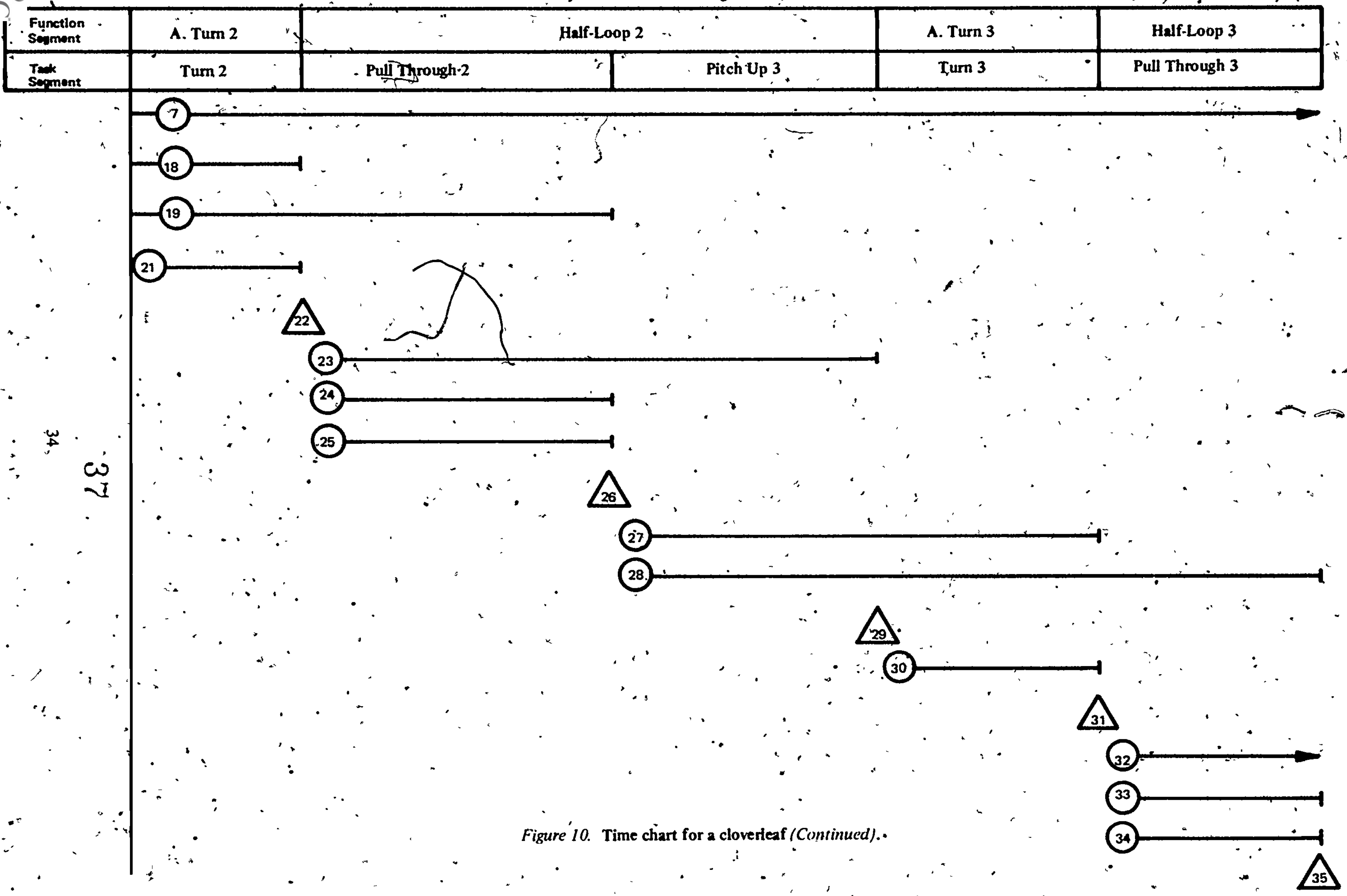


Figure 10. Time chart for a cloverleaf *(Continued)*.

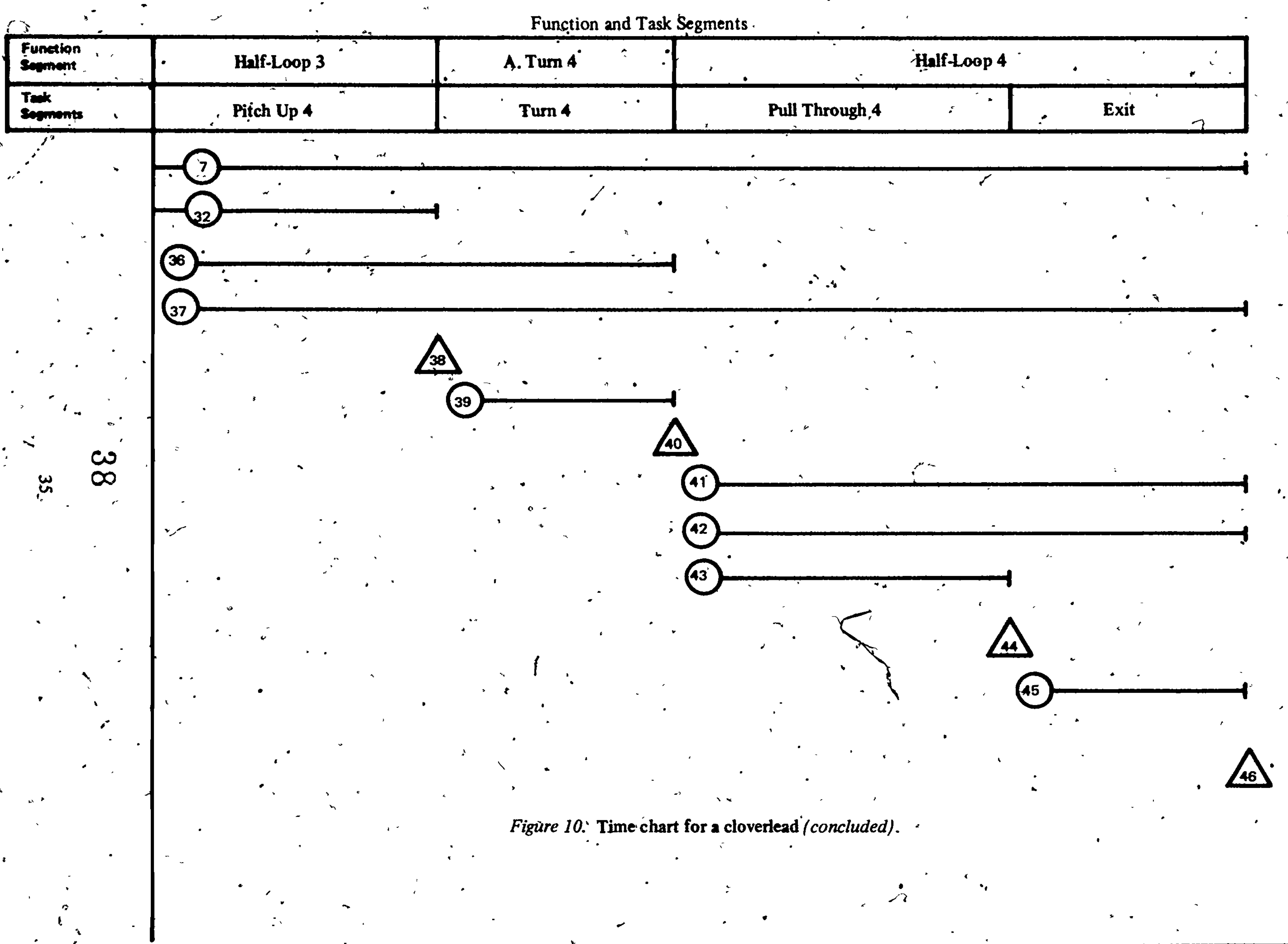


Figure 10. Time chart for a cloverlead *(concluded)*.

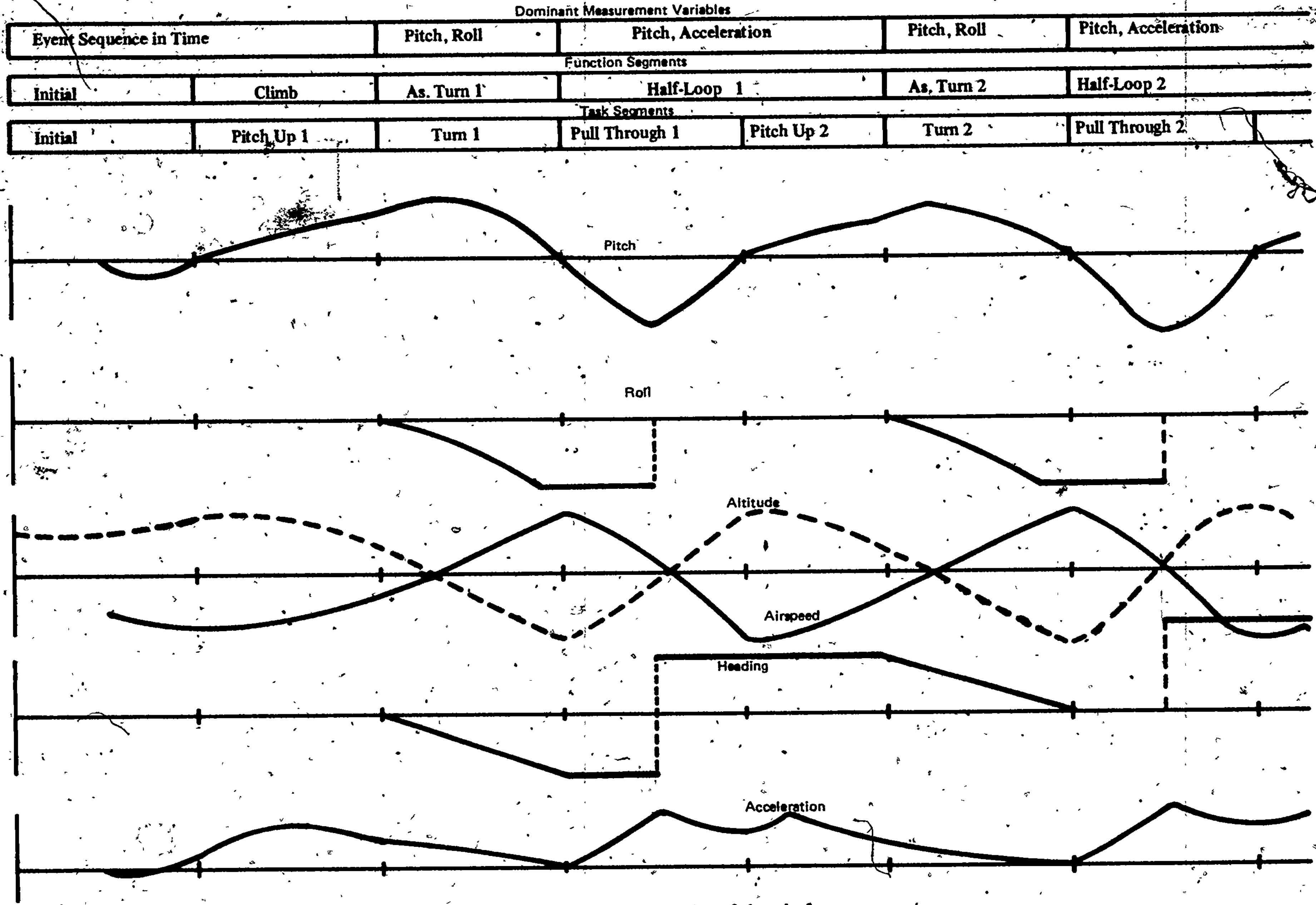


Figure 11. **Segmentation of cloverleaf.**

V. SEGMENTATION LOGIC

Introduction

The function and task segmentation, as discussed in Section IV, is implemented in the computer processor by a set of segmentation logic functions. This logic automatically divides each maneuver into the desired segments by identification of the proper start and stop conditions for each segment. Detailed logic equations are presented in (Connelly et al., 1974). In this section, we present a brief description of cues used for detecting task segment boundaries.

Automatic Segmentation Logic

The segment numbers and names for the Lazy 8 are shown in Figure 12. The processor automatically determines a new segment upon identification of the proper segment start condition. The end condition for a segment is the start condition of the next segment. The general logic for the Normal Landing, Barrel Roll, Split S, and Cloverleaf is shown in Figures 13, 14, 15, and 16, respectively.

VI. GENERATION OF MANEUVER REFERENCE CRITERION FUNCTIONS BY REGRESSION ANALYSIS

Reference Functions

In order to develop candidate proficiency measures it is first necessary to establish a reference (criterion) maneuver trajectory or trajectories for each maneuver type. This reference is to be used for comparison with student flights in order to implement error measurements. Generally the required reference functions are developed from maneuver specifications; however, the maneuver specifications do not identify a unique reference trajectory. The question then is: "Is there more than one way to fly the maneuver and achieve excellent performance?" If so, we then need to know if there is a manifold of acceptable trajectories or are there clusters of trajectories which can be distinguished. One reason a manifold of trajectories may appear when examining high performance data (i.e., flight performance rated excellent) is that trajectory parameters are required. For example, the form of the reference trajectory may be a function of initial aircraft states (attitudes, airspeed, and altitude). Likewise, there is need to investigate the relationship of proper flight in one segment to that achieved in another segment. For example, the second half of the Lazy 8 is to be an image of the first half of the Lazy 8; therefore, the reference maneuver for the second half of the maneuver is based on flight patterns produced in the first half.

The approach used here is to examine flight data from those flights rated excellent and determine if these flights satisfy the specifications and are closely grouped together. The specific question to be answered is: "Does the average over these test flights represent a suitable reference maneuver?" The variance of these test flights is used as one method of judging whether or not the average trajectory is a suitable reference trajectory. For example, if all the high performance test flights are grouped closely together, (i.e., with a small variance compared to the variance obtained from the other performance extreme; i.e., neophyte student pilot flights), the average of the high performance flights can provide a suitable reference maneuver. An illustrative example of this situation is shown in Figure 17. If it is shown that the high performance flights show several clusters, a reference function can be constructed for each cluster.

A further possibility is that a manifold of high performance flight trajectories may appear, all members of which satisfy maneuver specifications. In such a case, all these maneuvers are satisfactory, but one is to be preferred since it also satisfies some addition criterion (such as maximum "flight smoothness"). In this case, there is a region of acceptable performance and one trajectory in that region is recognized as superior.

An alternative way of specifying a maneuver reference is to not seek an isolated reference trajectory, but instead seek a reference rate of change of each critical flight variable within the flight envelope. For example, we would seek to represent the desired rate of change of pitch angle as a function of pitch, roll, yaw, airspeed and perhaps a maneuver state indicator in lieu of expressing pitch directly as a function of

Segment Number	Name	Start Condition
1	Straight and Level	Tape Mark
2	First Quadrant	$\theta > 10^{\circ}$
3	Second Quadrant	$\lvert\psi - \psi_o\rvert = 45^{\circ}$
4	Third Quadrant	$\lvert\psi - \psi_o\rvert = 90^{\circ}$
5	Fourth Quadrant	$\lvert\psi - \psi_o\rvert = 135^{\circ}$
6	Fifth Quadrant	$\phi = 0^{\circ}$
7	Sixth Quadrant	$\lvert\psi - \psi_o\rvert = 135^{\circ}$
8	Seventh Quadrant	$\lvert\psi - \psi_o\rvert = 90^{\circ}$
9	Eighth Quadrant	$\lvert\psi - \psi_o\rvert = 45^{\circ}$
	Stop	$\phi = 0^{\circ}$

Figure 12. **Segmentation logic for lazy 8.**

Segment Number	Name	Start Condition
1	Entry	Tape Mark
	(45° Turn)	$\lvert\phi\rvert > 10^{\circ}$
2	Initial	$\lvert\phi\rvert < 5^{\circ}$
3	Pitchout	$\lvert\phi\rvert > 15^{\circ}$
4	Downwind	$\lvert\phi\rvert < 5^{\circ}$
5	Final Turn	$\lvert\phi\rvert > 10^{\circ}$
6	Final Approach	$\lvert\phi\rvert < 5^{\circ}$
7	Roundout	Throttle = 45%
8	Touchdown	Altitude = 0

Figure 13. **Segmentation logic for normal approach and landing.**

Segment Number	Name	Start Condition
1	Initial	$\theta = -4^0$
2	Entry	$\vert\phi\vert = 5^o$
3	First Quadrant	$\vert\phi\vert > 5^o$
4	Second Quadrant	$\vert\phi\vert = 90^o$
5	Third Quadrant	$\phi = 180^o$
6	Fourth Quadrant	$\vert\phi\vert = 90^o$
	End	$\phi = 0^o$

Figure 14. Segmentation logic for barrel roll.

Segment Number	Name	Start Condition
1	Initial	Tape Mark
2	Entry	$\theta > 5^{\circ}$
	(Inversion)	$\lvert\phi\rvert > 9^{\circ}$
3	Pull Thru:to 90°	$\theta = 0^{\circ}$
	:to 0°	$\theta = \theta_{Min}$
4	Exit	$\theta = 0^{\circ}$

Figure 15. **Segmentation logic for split S.**

Segment Number	Name	Start Condition
1	Initial	Tape Mark
2 (Leaf 1)	Pitch Up	$\theta > 5^{\circ}$
3	Turn	$\theta > 40^{\circ}$
4	Pull Thru: to -90°	$\phi = \phi_{Min}$
	: to 0°	$\theta = \theta_{Min}$
	(End of Pull Thru)	$\theta = 0^{\circ}$
5 (Leaf 2)	Pitch Up	$\theta > 5^{\circ}$
•	•	•
•	•	•
•	•	•
(Leaf 4)	(End of Pull Thru)	$\theta = 0^{\circ}$
	End	$\theta = 0^{\circ}$ (Leaf 4)

Figure 16. **Segmentation logic for cloverleaf.**

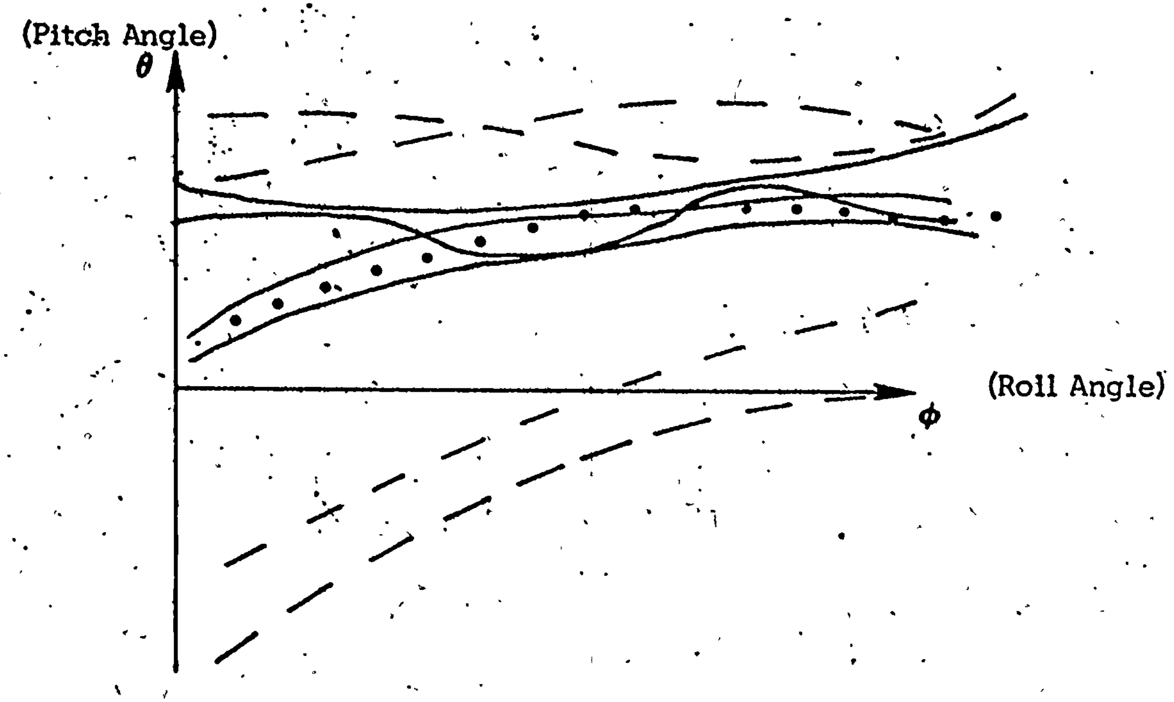


Figure 17. **Example of reference trajectory.**

airspeed, roll, etc. The reason a variable rate of change as a function of the aircraft flight variables is used is that the integral form (and associated initial conditions) is not required. Instead of constraining the formulation to representing a specific reference in a given function space, the rate expression is used so that the reference maintains a general applicability no matter where the flight path initiates. An example of this method of representing a reference maneuver is shown in Figure 18. It is seen that with this approach, an isolated trajectory reference is not acquired. It is also observed that high performance flight data over the maneuver envelop is required.

Regression Analysis Technique

A least squares regression analysis was performed on excellent rated performance demonstration data to generate the desired reference functions for each maneuver segment. The specific functions that were generated are defined in Section VII of this report.

The regression analysis is performed in an iterative way so that new data can easily be added as it becomes available. The method is discussed fully in Connelly et al., (1974).

VII. CANDIDATE MEASURES

General

As discussed in Sections III and IV, maneuvers are partitioned into function segments and task segments. A function segment is that portion of a maneuver in which the set of dominant measurement variables is consistent. A task segment is that portion of a function segment in which the relationship among dominant measurement variables is consistent. Pilot tasks required in each function segment can be further categorized as locus (continuous) segments, and sequential segments (event tasks) where the locus and sequence segments are not necessarily mutually exclusive. For example, several discrete tasks may be required in a locus segment. Thus, a portion of a maneuver could be simultaneously treated as a locus segment, as well as a sequence segment. Evaluation of pilot performance during that portion of the maneuver would necessarily be a combination of the separate locus and sequence segment evaluations Finally, it is noted that continuous operations can be treated as discrete events provided a threshold is established to define a region of acceptable performance.

Locus (continuous) and sequence (event) segment task categories identify two types of pilot tasks. Within the set of system tasks of which pilot tasks are a subset, an additional task category of system output tasks can be identified. This category includes those tasks which can be directly measured with the aircraft's flight variables. These are:

a. Establishment tasks which establish a specified condition, for example, altitude, heading, or rate of turn.

b. Maintenance tasks which maintain a constant condition such as constant altitude.

c. Recovery tasks which recover from a flight error condition, for example, recovery from a glide path error.

d. Coordinated tasks which conduct a coordinated maneuver where one or more control variables are coordinated with a reference variable, for example, a climbing turn.

Continuous task types (b) and (d) are usually associated with a reference or criterion function which provides a reference flight trajectory. These reference trajectories are part of the maneuver specification. As indicated, maneuver specifications do not always define a unique aircraft trajectory. In some cases there may be more then one way to fly the maneuver in order to satisfy the specifications. Therefore, either many flight trajectories are acceptable under the maneuver specifications; i.e., there are regions of acceptable flight trajectories, or, there are additional criterion functions (for example, "flight smoothness") that can be used to select a preferred trajectory from those which satisfy the maneuver criteria. Thus, while a manifold of trajectories is acceptable, one of the trajectories may be preferred if it best satisfies additional criteria.

Reference aircraft trajectories and maneuver specifications are generally not available for task types (a) and (c). Perhaps this is because there are many possible initial conditions for establishing a specified

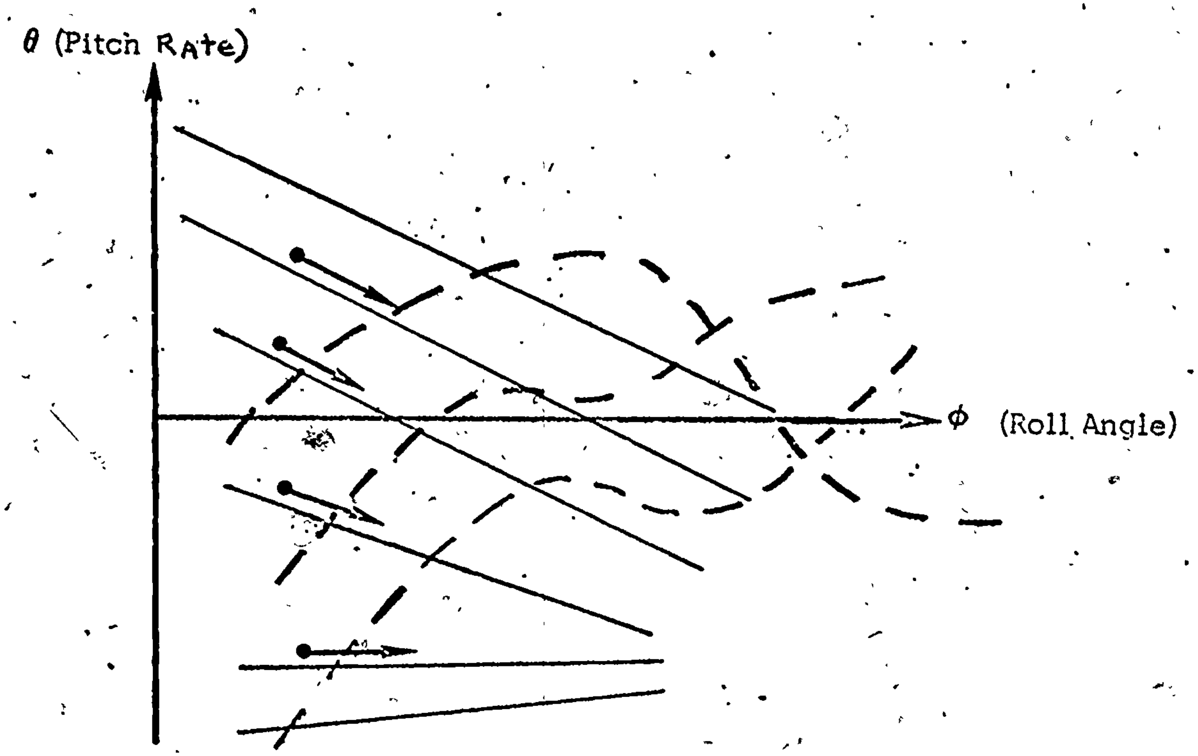


Figure 18. **Example of reference vector (differential).**

condition. Likewise, the number of possible error recovery situations is large. Another reason for the lack of specifications for recovery tasks may be that methods of defining the recovery specifications may not have been apparent.

Measure Definitions and Notation

a. *Continuous Flight Tasks.* Some continuous flight tasks, such as those requiring maintenance of a constant condition, or achieving a coordinated maneuver, can be associated with a specific reference trajectory. Because of this, candidate proficiency measures can be constructed with respect to this reference trajectory. An error function can be constructed as a difference between the criterion reference function and the actual flight trajectory as shown in Figure 19. The candidate measure could be defined as a function of, perhaps, the absolute value of that error measure.

It is also possible to construct a tolerance about the reference function which reflects the region of acceptable flight, as shown in Figure 20. This tolerance need not be constant and, indeed, can vary along the flight path. In this case, small variations about the reference flight path are ignored until the actual flight path exceeds the tolerance whereupon an error event is generated. Thus, proficiency measurement of flight tasks for which continuous references are available, can be treated by either continuous error functions or by discrete error events.

An alternate way of representing the reference of a desired maneuver is via a difference equation. This equation specifies the desired rate of change of each flight variable of interest as a function of state variables:

$$\Delta X_i = \Delta X_i(X_j) = \Delta X_i(X_1, \ldots, X_n)$$

where X_j is a state variable.

A reference (criterion) maneuver can be considered as a vector with components corresponding to the desired rate of change in the state variables. This is illustrated in Figure 21 in the simplest case of a two space representation. The vector difference between the reference and actual vectors is expressed as

$$D = \left[K_1^2 (\Delta X_{1R} - \Delta X_{1A})^2 + K_2^2 (\Delta X_{2R} - \Delta X_{2A})^2\right]^{1/2}$$

where

D = difference vector length

K_1 = weighting function for the state variable X_1 rate of change

K_2 = weighting function for the state variable X_2 rate of change

The K_i functions are included in order to provide for a sufficient degree of generality in the applications. In general, the vector difference will be expressed as:

$$D_j = \left[\Sigma K_i^2 (\Delta X_{iR} (\overline{X}) - \Delta X_{iA} (\overline{X}))^2\right]^{1/2}$$

where

$D_j = D(\overline{X})$

In such a case, the distance from the actual vector projected to the reference vector may be the salient variable. Let us represent this error vector and its length as

$$E_j = D_j \sin \delta$$

where

E is the error vector length and δ is the angle the difference vector makes with the reference vector.

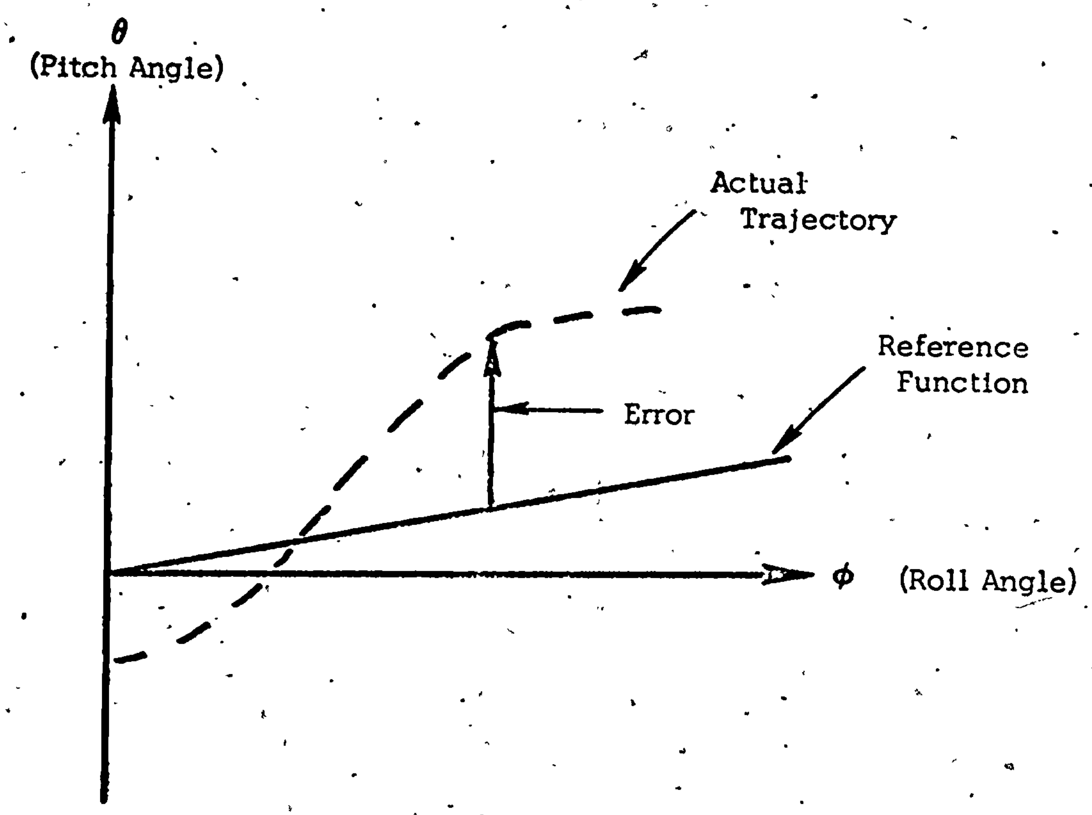


Figure 19. **Continuous difference measures.**

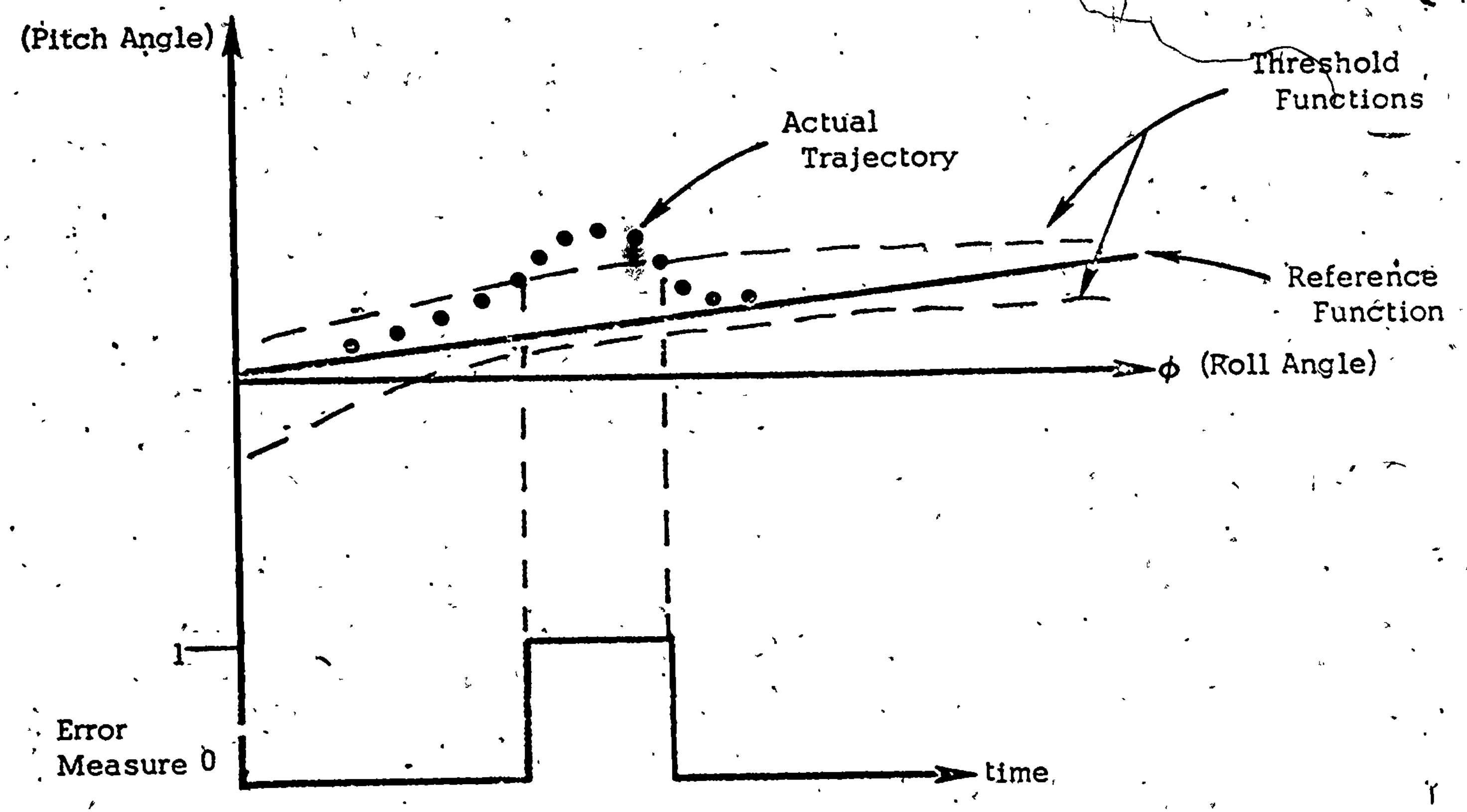


Figure 20. Threshold error measures.

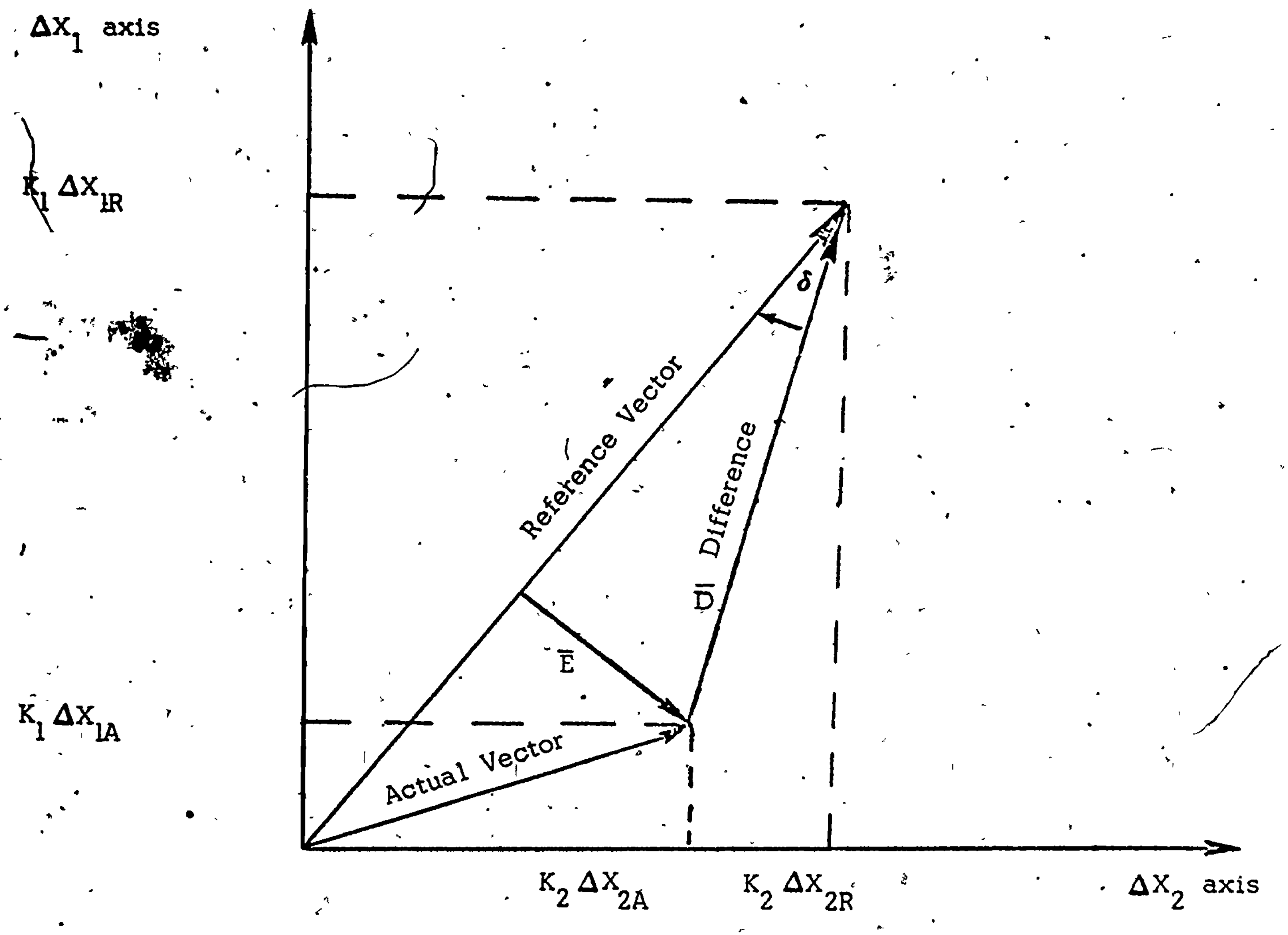


Figure 21. **Differential error measures.**

b. *Discrete Flight Tasks.* Discrete tasks are associated with either a continuous variable where the task is to be accomplished within certain values of that continuous variable, or they are associated with other discrete events where the event is to occur in some specified sequence. If the event is referenced to a continuous variable, two types of measures are possible. One type of measure is a Boolean measure which indicates whether or not the event took place within the prescribed limits of the continuous variable, as shown in Figure 22. If the event does not occur within that prescribed interval, an error measure indicating the extent of out of tolerance may be useful. This type of error measure is illustrated in Figure 23. Figure 24 illustrates the measurement of sequential error where we require that the event under test occur after event A and before B. This leads to a Boolean measurement that the correct sequence has occurred.

Proficiency Measurement Concepts

The types of error measures identified above can be used in several ways. The way that an error is measured can be selected based on whether that error is the primary or secondary concern in measuring proficiency. For example, the primary errors might be measured with the continuous difference method (Figure 19) and secondary or lesser important errors measured with the threshold technique (Figure 20). The combined measure would consist essentially of the continuous factor unless the threshold was exceeded. Therefore, the combined measure would emphasize the primary error factors and de-emphasize the secondary error factors unless the secondary factors became sufficiently large. The primary error measures might be those associated with tasks judged to be difficult or otherwise judged to be important to that maneuver. Likewise the secondary errors might be associated with tasks judged to be easy, for example, maintaining a constant value of a variable such as altitude or heading.

Error measures can also be made functions of variables other than error terms. For example, the weighting of an error can be based on whether or not the error is diverging or converging. Also, the weighting of an error term can be a function of a discrete variable so as to change the importance of error depending on concurrent activity.

a. *Methods of Combining Measures.* A task segment may contain various types of tasks. As a result, it is necessary to combine the candidate proficiency measures from each task in order to form a candidate segment measure. Likewise it is desirable to combine segment measures from each segment in the maneuver to form an overall maneuver measure. There are several ways of combining the candidate measures and each can be tested to determine which method provides best discrimination of extreme performance. Four methods of combining segment measures are as follows:

1. Linear sums with the weighting terms determined by:
   a. Relative variance of the individual measures, and
   b. Capability of the individual measures to separate extreme performance.
2. Selection of the largest error term.
3. Discrete factor parameterization of continuous error measures.
4. Maintain the individual error components in vector form.

The linear-sum-combined measure allows individual weighting of each error component, with each error term thereby contributing to some extent to the combined measure. The measure obtained in selection of the maximum or largest error term is very sensitive to one error factor and, therefore, would be very responsive to the pilots' attempts to improve that flight factor. Discrete factor parameterization of continuous error measures allows a different weighting of continuous measures based on other (discrete) pilot actions. For example, it is possible to weight the importance of, say, an altitude hold error as a function of other tasks he might be performing such a communication tasks. This recognizes that proficiency may be a function of how well a continuous task is performed when the pilot is attempting to accomplish a secondary task. Finally, the rationale for a vector performance measure, where each vector component is a summary measure for a type of task, is that the combination of performance measures from similar types of tasks provides separate proficiency measurements for each different type of task. Thus, it is preferred to combine (e.g., by addition) measures of similar tasks from one segment to another. The resultant of this combination is a maneuver vector with components which provide a measure of proficiency for n different pilot skill areas.

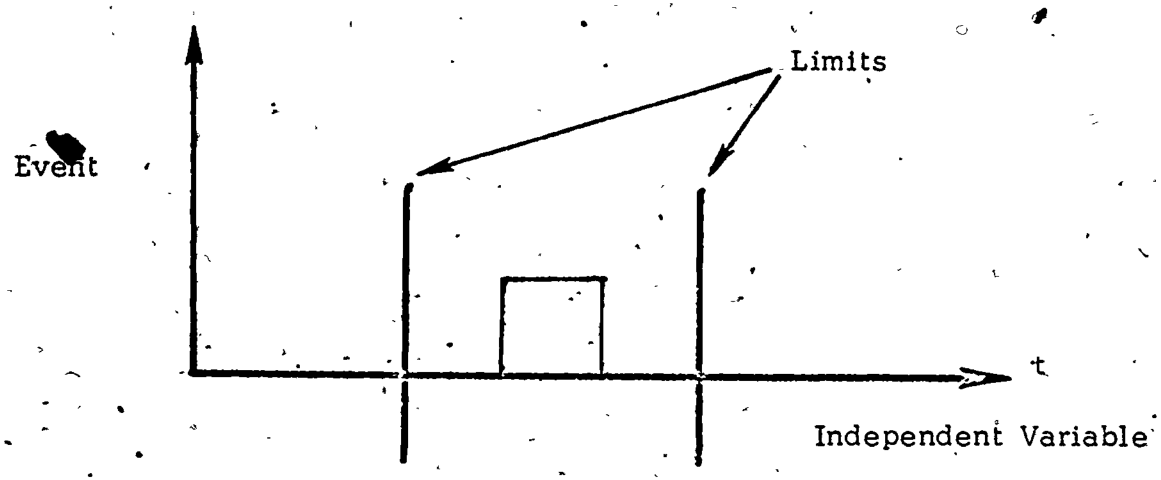


Figure 22. **Measurement of event occurrence.**

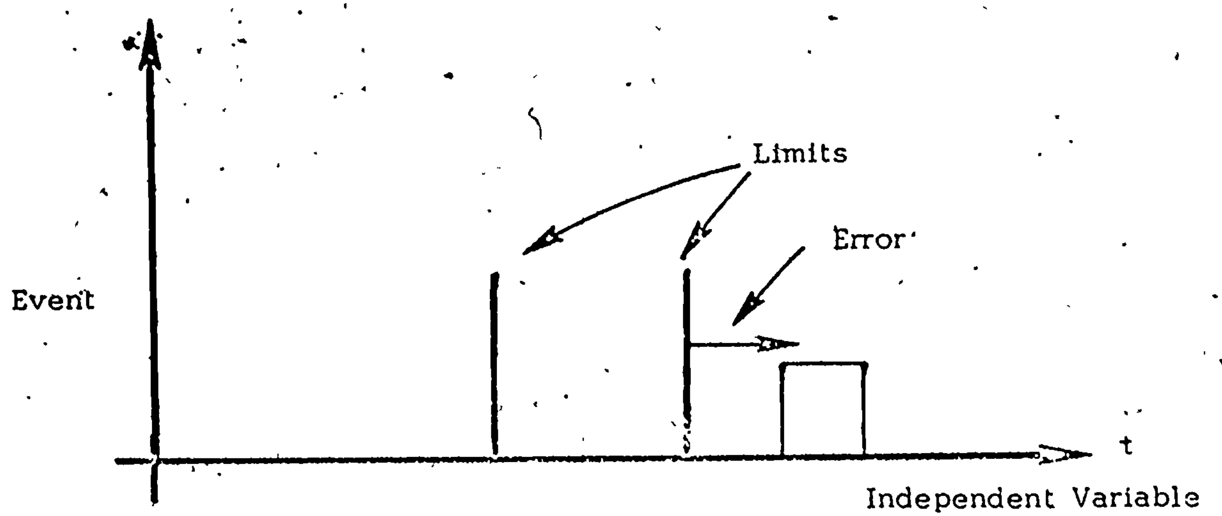


Figure 23. **Continuous measurement of event error.**

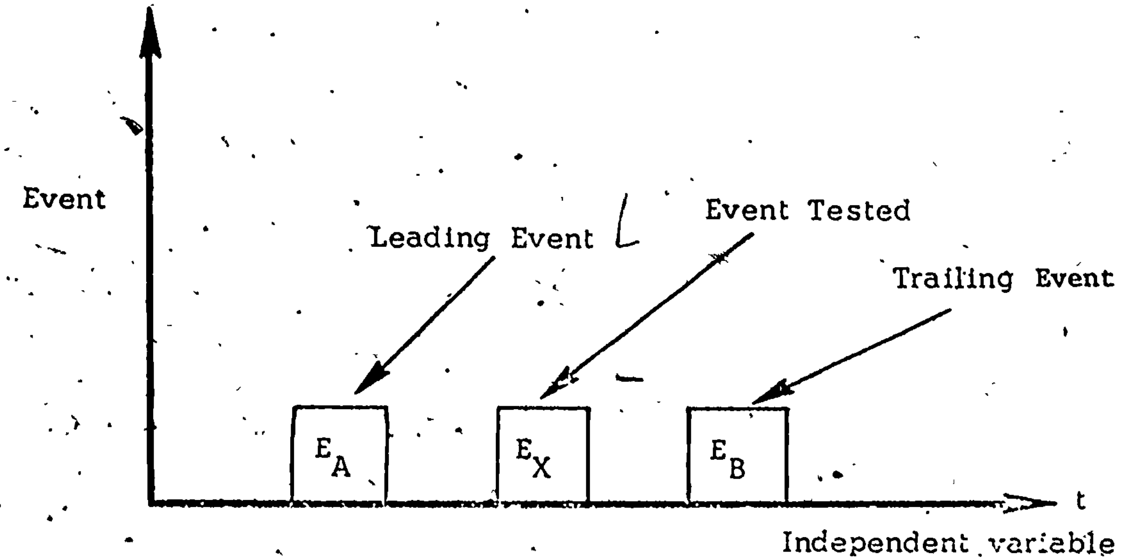


Figure 24. **Sequential measurement of event occurrence.**

The n components of the vector are the proficiency measures for the n different types of flight factors. A subsequent combinational operation can yield a single maneuver proficiency measure if desired

Definition of Error Measures

Previous sections have identified several primary error measurement techniques as well as several possible operations on those measures. Since the initial result of the maneuver analysis is the development of candidate proficiency measures which are to be subsequently tested with flight data, the number of combinations of measures and operations on measures can be large. This could lead to a clumsy documentation system unless some convenient compact notation is employed. Thus we first must develop acceptable notation before operations are possible on error measures. This notation should identify variables, parameters, and tolerance values of interest in addition to providing the information required to implement the primary error measures on flight data.

a. *Continuous Difference Error Measures.* A reference trajectory is formed as:

$$\overline{X_i} = f_i(Y_1, Y_2, \ldots, Y_n) \tag{1}$$

where

X_i is a flight variable treated as a dependent variable for the purpose of establishing maneuver criteria, i distinguishes this reference trajectory from others; $Y_1, Y_2, \ldots, Y_n$ are flight variables treated as independent variables for the purpose of establishing maneuver criteria, f_i is the function relating the flight variables and defines the maneuver criterion function. Note that $\overline{X_i}$ is the predicted value of variable X (determined from high performance flight data) in a given segment in the maneuver, and that the dependent variable as well as all of the independent variables are functions of time. An example of equation (1) would be

$$\overline{\theta} = f(\phi, \Delta AS) \tag{2}$$

The corresponding primary difference error measure as illustrated in Figure 17 is

$$E_{Mi} = \{X - f_i(Y_1, Y_2, \ldots, Y_n)\} = E_{Mi}(X; Y_1, Y_2, \ldots, Y_n) \tag{3}$$

where

subscript M indicates the error measure is a mean of difference from a reference trajectory function. Therefore, in summary the notation

$$E_{Mi}(X; Y_1, Y_2, \ldots, Y_n) \tag{4}$$

indicates a mean trajectory criterion function is used, X being the dependent variable, and i identifying a specific function. The error chosen for E_M is the mean absolute deviation given explicitly as

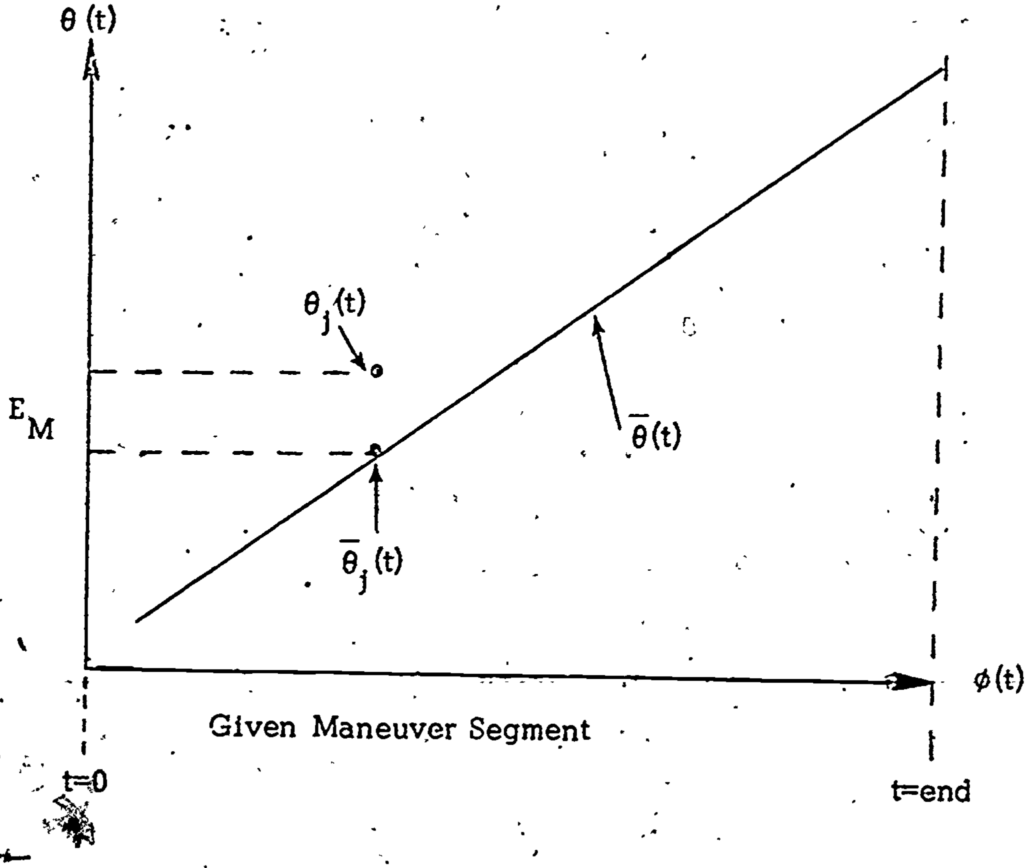
$$E_M = 1/n \sum_{i=1}^{n} |X_i - \overline{X}_i| \tag{5}$$

This error measure can be exemplified in this manner:

$$\text{Let } X = \theta, Y_1 = \phi, Y_2 = \Delta AS; \tag{6}$$

then $\overline{\theta} = f(\phi, \Delta AS)$

where $\overline{\theta} = \overline{X_i}$ for some i as shown in Figure 25.



$$E_M = \frac{1}{n} \sum_{j=1}^{n} \left| \theta_j - \bar{\theta}_j \right|$$

$\bar{\theta} = f(\phi, \Delta AS)$

θ_j (t) is a pitch angle data sample at t

$\bar{\theta}_j$ (t) is the value of the criterion function at t

Figure 25. Error type E_M.

b. *Threshold Error Measures*. Associated with the described mean reference function $\overline{X_i}$ is the standard deviation function $X_{\sigma i}$. A representation of this measure appears in Figure 26. A threshold error function can be constructed from $X_{\sigma i}$, as follows:

$$\left.\begin{array}{l} E_\sigma = 0 \text{ if } |E_M| < K\sigma \\ \\ E_\sigma = 1 \text{ if } |E_M| \geq K\sigma \end{array}\right\} \tag{7}$$

and

$$E_{\sigma i} = E_{\sigma i} (K; X; Y_1, Y_2, \ldots, Y_n) \tag{8}$$

The parameter K specifies the number of standard deviations and i distinguishes among the E_σ.

c. *Differential Difference Error Measures*. A differential or difference equation representation of the high performance maneuver flights can also be used as a maneuver criterion. Let the corresponding criterion be represented as follows

$$\overline{DX} = g_i (X; Y_1, Y_2, \ldots, Y_n) \tag{9}$$

where $\overline{DX}$ indicates mean change (mean over excellent category flights) in variable X over time period Δt. Note that X can be included in the argument. Subscript i is used to identify a particular function. The corresponding error is

$$e_X = \frac{1}{N} \sum_{i=1}^{N} DX - g_i = e_X (X; Y_1, Y_2, \ldots, Y_n) \tag{10}$$

and the total measure over all variables is:

$$E_{Dj} = \sqrt{\sum_i e_i^2}, i = X_1, X_2, \ldots, X_k \tag{11}$$

$$E_{Dj} = E_{Dj} (X_1, X_2, \ldots, X_k, Y_1, Y_2, \ldots, Y_n) \tag{12}$$

where j indicates a particular set of difference functions.

d. *Discrete Task Error Measures*. In reference to Figures 22, 23, and 24, it is seen that discrete task errors are measured by observing the value of a continuous variable when the task is accomplished successfully or observing the preceding and succeeding tasks. Consider the value of variable (V) when discrete task X is completed; e.g., when X=1 test value of V.

An event (discrete task) error can be formulated as

$$E_E = 0 \text{ if } V_{T1} \leq V(X) \leq V_{T2} \tag{13}$$

$$E_E = 1 \text{ if } V(X) > V_{T2} \text{ or } V(X) < V_{T1}$$

Note that

$$E_E = E_E (X; V_{T1}, V_{T2}; V) \tag{14}$$

ERROR TYPE E_σ, E_σ $(2, \theta; \phi, \Delta AS)$

$$d_i = \theta_i - \bar{\theta}_i$$

$$e_i = 0 \text{ for } -f_{2\sigma} < d_i < f_{2\sigma}$$

$$e_i = 1 \text{ for } d_i > f_{2\sigma}$$

$$\text{or } d_i < f_{2\sigma}$$

$$E_\sigma = \frac{1}{n} \sum_{i=1}^{n} e_i$$

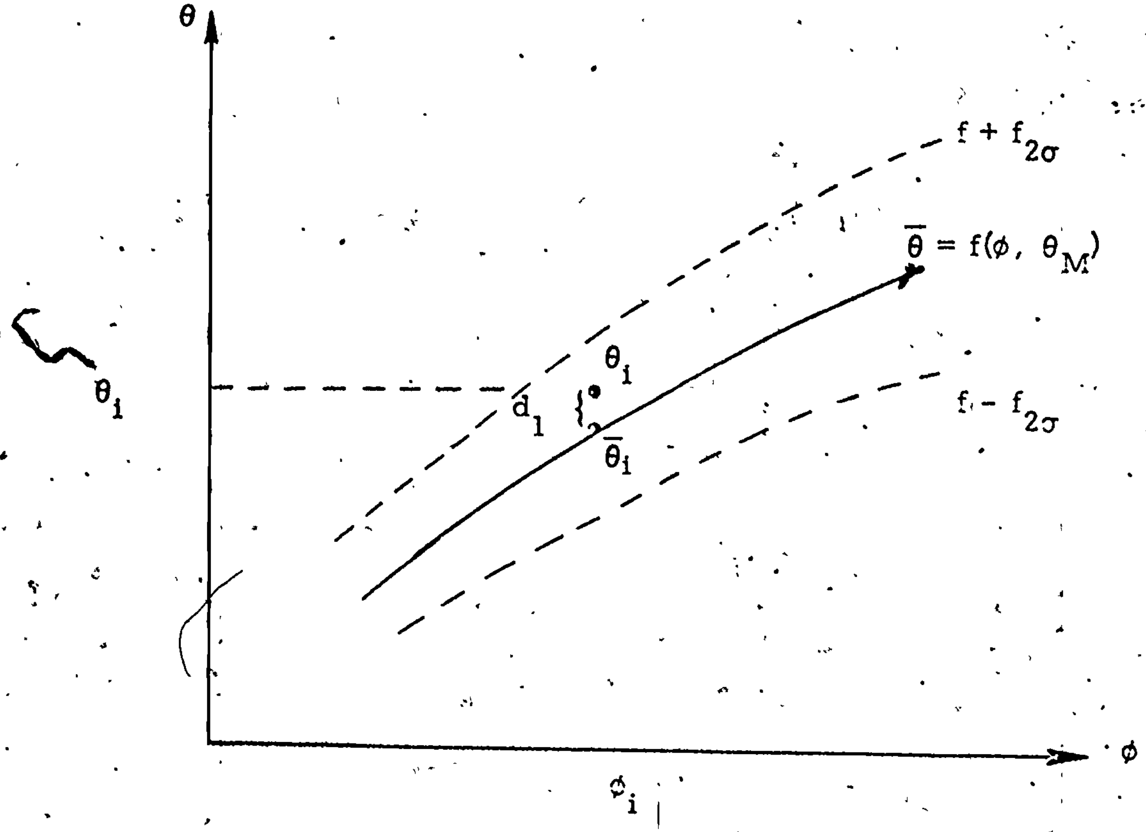


Figure 26. Threshold error measures.

where X identifies the event that triggers the measurement and V_{T2}, V_{T1} identifies the tolerance limits of the tested variable and V is the tested variable. Also V_{T1}, V_{T2} can indicate bounding discrete events for event sequence tests. Error function E_E is true whenever the tested variable value is not within the prescribed tolerance. Figure 27 shows an example of the usage of E_E.

An error measure that indicates the amount of out-of-tolerance is

$$E_{Vj} = \text{Max}\left\{ (V_{ref} - V_{T1}) - V, V - (V_{ref} + V_{T2}), 0 \right\} \quad (15)$$

Notation for this type of primary error is

$$E_{Vj}(X; V_{T1}, V_{T2}; V) \quad (16)$$

Figure 28 shows an example of the usage of E_V. In equation 16, V_{T1} represents the lower tolerance limit, V_{T2} the upper tolerance limit.

e. *Sample Error Measures*. In addition to error measures, it is desirable to sample the value of specified variables at specific times during the maneuver segment. For example, a maximum or minimum may be required. Notation for this measure is

$$E_{Sj}(Y; X) \quad (17)$$

where E_S indicates a sampled measure, j the number of the measure, X the variable to be sampled, and Y the condition for sampling. For example, if we want to measure heading ψ when roll angle reaches zero, the notation would be

$$E_{Sj}(\phi = 0; \psi). \quad (18)$$

Also, if we want to measure maximum pitch angle the notation would be

$$E_{Sj}(\theta_{Max}; \theta). \quad (19)$$

f. *Miscellaneous Error Measures*. The trigger variable identified as X in Equations 13, 14, and 16 can use several conventions, each of which indicates when a test is to be performed. One notation used is a logic notation, e.g., $x = 1, \theta = 0$. Another notation is θ_{oi} and θ_{mj} where θ_{oi} refers to the ith time θ is zero during the maneuver and θ_{mj} refers to the jth time θ reaches a maximum or minimum during the maneuver. Thus, if a measurement is desired on say ϕ when θ reaches the first extremum (say max), the notation could be

$$E_{Ei}(\theta_{m1}, -2^\circ, +2^\circ, \phi). \quad (19)$$

This error measure notation specifies that when θ reaches its first extreme value, test ϕ for a zero value $\pm 2^\circ$.

Previous error measures were defined with single index systems. This might be insufficient to take care of all cases so a double index system may be useful, to wit, E_{Vkj} and E_{Eij}.

Operations on Error Measures

The described error measures are the raw data from which candidate proficiency measures are to be derived when judiciously chosen operations are performed on such data. These operations are described in the following paragraphs.

a. *Linear Sums*. One type operation is the sum of weighted measures. This can be mathematically expressed as:

$$P_K = \sum_i W_i E_{Zi} \quad (20)$$

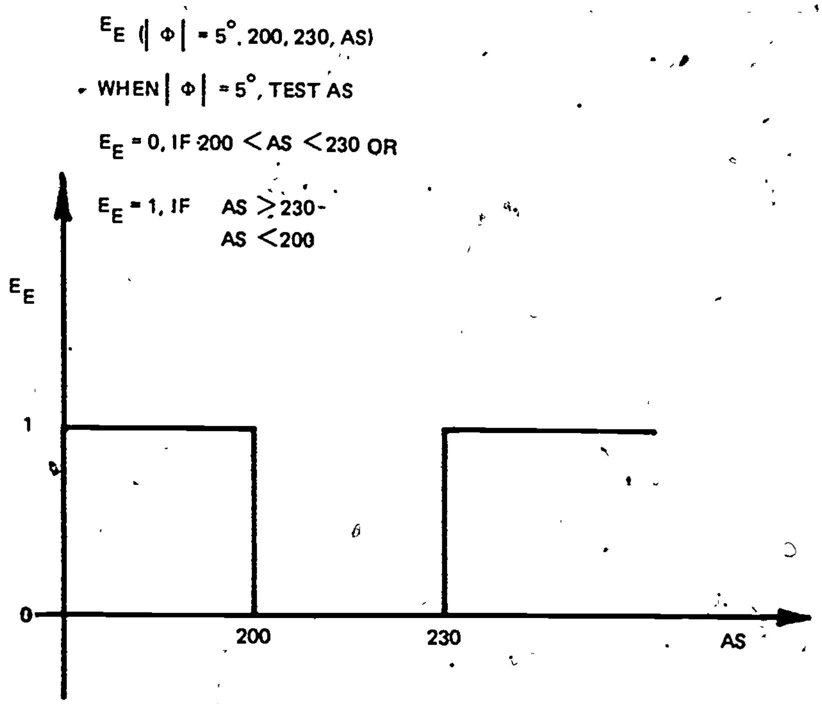


Figure 27. **Error type E_E.**

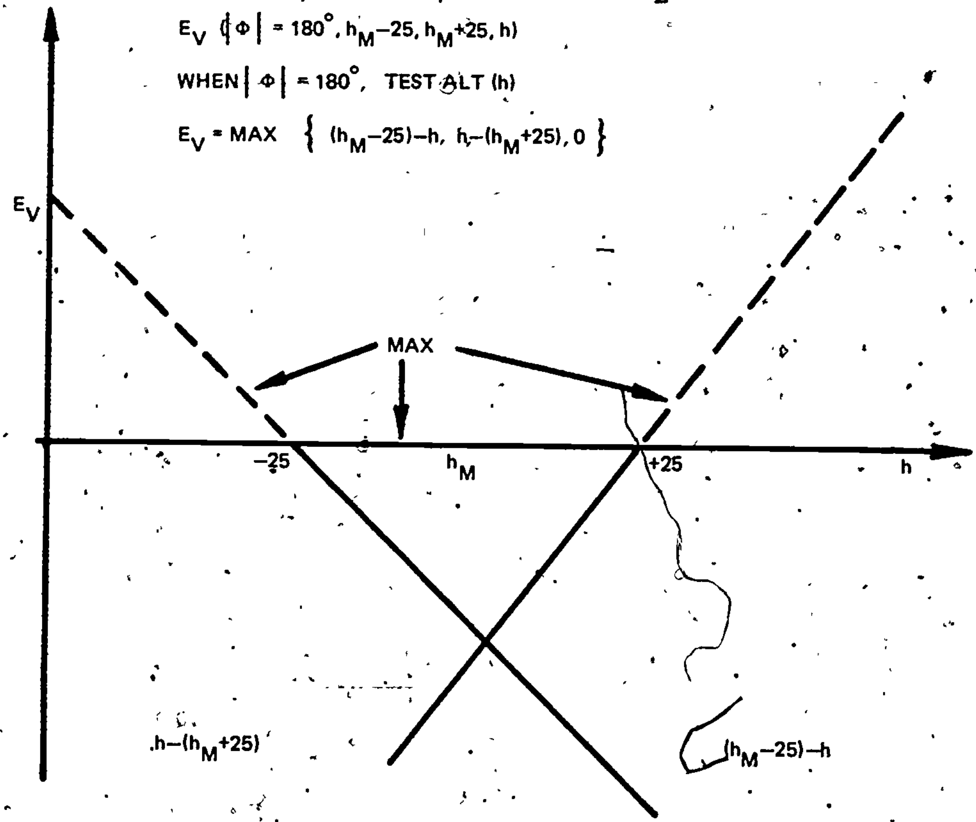


Figure 28. **Error Type E_V.**

This function can be represented as

$$P_K (E_1, \ldots, E_K) \tag{21}$$

where E_K can be an error measure or a sum of error measures. The subscript K indicates a weighted sum is used. Equation 20 is in generalized form and can be made specific thusly:

$$P_K = \frac{1}{K} \cdot \sum_{i=1}^{K} W_i E_{Zi} \tag{22}$$

The weights W_i may be computed in any of several alternative ways. The optimal way is unknown and depends to a great extent on the nature of the measures to be weighted and summed. In some cases, weighting may not be appropriate at all, in which event the W_1 would be set to 1. In other cases weights might be derived by regression analyses using some known index of skill (independently derived measure) employed as a basis for overall performance discrimination. In still other cases, it may be desired to study the weighting of individual measures in a way which produces a weighted summary measure satisfying some fundamental measurement theory or concept. An example of the latter would be the concept of minimum performance variance in highly skilled performers, in which case an experimental weighting technique which achieves variance-minimization would be explored.

In view of the many weighting alternatives that exist, no one method was singled out for application to all measures in all segments of the various maneuvers under study. Instead, a capability was developed to permit study of any technique by allowing the researcher to specify the desired method for each case. A "minimum variance" method, for instance, was developed mathematically (Appendix A) and implemented in the software research system, however its use is optional, allowing it to be studied comparatively with other alternative methods.

b. *Divergence/Convergence Weighting*. An error can be weighted based on the sign of its derivative. Thus, if

$$\begin{aligned} &|E_K(j)| \leqslant |E_K(j+1)|, W_K = 1 \\ &|E_K(j)| > |E_K(j+1)|, W_K = 0, \end{aligned} \tag{24}$$

where the subscript j denotes specific time samples. This can be expressed compactly as:

$$P_{dj} (E_1, \ldots, E_K) \tag{25}$$

c. *Maximum Term*. Another method of combining measures is by the selection of the largest error term

$$P_{Max_k} (W_i, E_i) = \mathrm{Max}\left\{ W_1 E_1, \ldots, W_N E_N \right\} \tag{26}$$

where W_i is a weighting factor on the error.

Weights for each error term are such that the expected value of each weighted factor for the excellent (IP) performance category are equal. These weights once determined, are used to form the candidate proficiency measure P_{Max_K}.

d. *Discrete Factor Parameterization of Continuous Measures*. The discrete factor parameterization of continuous error measures is used to provide differential weighting of continuous task errors as a function of the existence of discrete tasks (a secondary task). For example, notation for the operation is

$$P_{Pj} = P_{Pj}(X_1; E_i) \tag{27}$$

W_i is the weighting factor value of E_i. When discrete factor X_i is true, $W_1 = K_1$ and when X_i is false, $W_1 = K_i'$. Optimum values for K_i, K_i' have not been established.

e. *Vector Operation*. The final operation provides individual error components in vector form. This can be represented as "vector addition"

$$P_{\rightarrow} = \bar{e}_E \sum_i E_{Ei} + \bar{e}_\sigma \sum_i E_{\sigma i} + \bar{e}_M \sum_i E_{Mi} + \bar{e}_V \sum_i E_{Vi} + \bar{e}_D \sum_i E_{Di} \tag{28}$$

where $\bar{e}_E, \bar{e}_\sigma, \bar{e}_M, \bar{e}_V$ and $\bar{e}_D$ are orthogonal unit vectors.

The notational expression is

$$P_{\rightarrow}(E_1, \ldots, E_K) \tag{29}$$

A generalized "vector addition" can be used to process measures of similar types of tasks rather than types of measures as shown above.

VIII. SEGMENT AND MANEUVER MEASURE FORMULAS

This Section documents the specific formulas for candidate measures for each of the five maneuvers. The measure types (e.g., EM, EE, PK) and their parameters were described in detail in the preceding Section. Therefore, the definitions of parameters for each measure type, as provided in the following tables, completely define the measure formulas.

Table 6 presents the basic notation used throughout the subsequent measure specification Tables 7 through 21.

IX. OVERVIEW OF SOFTWARE FOR COMPUTING CANDIDATE MEASURES

Software was developed for computing user-specified measures from recorded operator performance data, and producing hard copies of results for analysis and subsequent validation tests. The software is designed to compute any measures of the general types discussed in Section VII. Specific measure formulae, as presented in Section VIII to document candidate T-37 measures, are represented by their parameters, specifiable at run-time by the user. Therefore, the software has utility for measurement studies additional to the T-37 problem addressed herein.

The software, implemented on a Sigma 5 computer,[1] performs the following tasks:

(1) Smooths data to remove noise and/or introduce special filtering in accordance with user's specifications.

(2) Produces print outs and plots of raw and smoothed data at sampling rates specifiable by the user.

(3) Automatically segments maneuvers in accordance with the task segmentation results documented in Section III.

(4) Computes criterion (reference) functions from sets of maneuver performances identified by the user (e.g., instructor pilot performances or those of skilled student pilots). Dependent and independent variables are specified at run time by the user.

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[1] The Sigma 5 is part of a Simulation and Training Advanced Research System (STARS) in the Advanced Systems Division, AFHRL, Wright-Patterson AFB, Ohio.

Table 6. Symbols

Symbol	Computer Variable	Definition
X		Boolean Variable
$\bar{X}$		NOT Operation on Boolean Variable
$\tilde{X}$		Memory Operation where if $X(t_o) = 1$, and $X(t) = 0, t < t_0$ then $X(t) = 0 \quad t < t_o$; $X(t) = 1 \quad t \geq t_o$
ψ	HEADG	Heading Aircraft
ψ_A	RUNWAY	Runway Heading
ϕ	ROLL	Roll Angle
ϕ_C		Roll Angle Required for Turn Coordination (see Appendix II)
θ	PITCH	Pitch Angle
θ_L	PITCHL	Pitch Angle for Level Flight
h	ALT	Altitude
$\dot{h}$	ARATE	Altitude Rate (feet/minute)
AS	AIRSPD	Airspeed
T	ENGINE	Engine (RPM)
g	NACCEL	Normal Acceleration
$\delta_{F\text{-}Long}$	$LOSF_L^R$	Longitudinal Stick Force
$\delta_{F\text{-}Lat}$	$LASF_L^R$	Lateral Stick Force
$\delta_{P\text{-}Lat}$	$LASP_L^R$	Lateral Stick Position
$\delta_{P\text{-}Long}$	$LOSP_L^R$	Longitudinal Stick Position
P	PRATE	Pitching Rate
q	QRATE	Rolling Rate
r	YRATE	Yaw Rate
A_y	LACCEL	Lateral Acceleration

Table 7. **Candidate Segment Measures for Split S**

Segment	EE X	EE V_{T1}	EE V_{T2}	EE V	EM X	EM Y	EV X	EV V_{T1}	EV V_{T2}	EV V
I. Initial	X_1	5000	25000	h			X_1	−3	+3	ϕ
	X_1	−3	+3	ϕ			$\widetilde{X}_1$	h_o-100	h_o+100	h
	$\widetilde{X}_1$	ψ_o-3	ψ_o+3	Ψ			$\widetilde{X}_1$	ψ_o-3	ψ_o+3	ψ
II. Entry	X_2	135	250	AS			$\widetilde{X}_2$	θ_M-6	θ_M	θ
	$\widetilde{X}_2$	ψ_o-3	ψ_o+3	ψ						
	$\widetilde{X}_2$	−3	+3	ϕ						
	θ_M	20	30	θ						
(Inversion)	X_3	118	122	AS			X_3	118	122	AS
	X_3	0	0	SB						
	$\widetilde{X}_3$	50	80	$\lvert q \rvert$						
	$\widetilde{X}_3$	ψ_o-3	ψ_o+3	ψ						
	ϕ_M	177	183	ϕ						
	ϕ_M	10	30	θ						
III. Pull Through:	$\widetilde{X}_4$	179	181	ϕ	G	θ	$\widetilde{X}_4$	179	181	ϕ
To 90°	$\widetilde{X}_4$	ψ_o-3	ψ_o+3	ψ	P	θ	$\widetilde{X}_4$	ψ_o-3	ψ_o+3	ψ
	$\widetilde{X}_4$	1	2.5	G	AS	θ				
					$\delta_{F\text{-Long}}$	θ				
To 0°	X_5	$\psi_o'+177$	$\psi_o'+183$	ψ	G	θ	X_5	$\psi_o'+177$	$\psi_o'+183$	ψ
	X_5	−1	+1	ϕ	P	θ	X_5	−1	+1	ϕ
	X_5	1	G_1	G	AS	θ				
					$\delta_{F\text{-Long}}$	θ				
IV. Exit	X_6	h_o-500	h_o	h			X_6	ψ_o+179	ψ_o+181	ψ

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Table 8. **Special Terms Used in Segment Measures Specification for Split S**

Term	Definition
X_1	Tape Mark
X_2	$\theta = 5$
X_3	$\lvert\phi\rvert = 9$
X_4	$\theta = 0$
X_5	$\theta = -90$
X_6	$\theta = 0$
ψ_o	$\psi(t_{X_1})$
h_o	$h(t_{x_1})$
ψ'_o	$\psi(t_{X_4})$
G_1	Upper Limit on G's (to be determined)

Table 9. **Segment and Maneuver Summary Measures for Split S**

Segment	Summary Measure
I. Initial	PK (EE, EV)
	PMAX (EE, EV)
II. Entry	PK (EE, EV)
	PMAX (EE, EV)
(Inversion)	PK (EE, EV, EM)
	PMAX (EE, EV, EM)
III. Pull Through:	PK (EE, EV, EM)
To 90°	PMAX (EE, EV, EM)
To 0°	PK (EE, EV, EM)
	PMAX (EE, EV, EM)
IV. Exit	PK (EE, EV)
	PMAX (EE, EV)
Total Maneuver	PK (PK)
	PMAX (PK)
	PMAX (PMAX)

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Table 10. **Candidate Segment Measures for Approach and Landing**

Segment	EE				EM		EO			EV			
	X	V_{T1}	V_{T2}	V	X	Y	K	X	Y	X	V_{T1}	V_{T2}	V
I. Entry	$\tilde{X}_1$	h_1-75	h_1+75	h			2	AS	T, θ, ϕ	$\tilde{X}_1 \cdot X_2$	ψ_1-3	ψ_1+3	ψ
	$\tilde{X}_1$	196	204	AS						$\tilde{X}_1 \cdot \tilde{X}_2$	ψ_2-3	ψ_2+3	ψ
	$\tilde{X}_1 \cdot X_2$	ψ_1-3	ψ_1+3	ψ									
	$\tilde{X}_1 \cdot \tilde{X}_2$	ψ_2-3	ψ_2+3	ψ									
	$\tilde{X}_1$	-5	$+5$	ϕ									
(45° Turn)	$\tilde{X}_3$	45	60	ϕ	q	ϕ, ϕ_{Max}							
	$\tilde{X}_3$	925	1075	h	$\dot{\phi}$	ϕ_c							
	$\tilde{X}_3$	196	204	AS									
II. Initial	$\tilde{X}_4$	ψ_A-3	ψ_A+3	ψ						$\tilde{X}_4$	ψ_A-3	ψ_A+3	ψ
	$\tilde{X}_4$	925	1075	h									
	$\tilde{X}_4$	196	204	AS									
	$\tilde{X}_4$	-5	$+5$	ϕ									
III. Pitch Out	$\tilde{X}_5$	925	1075	h	ϕ	$\phi_c, \psi-\psi_A$							
	$\tilde{X}_5$	45	60	ϕ	q	ϕ, ϕ_{Max}							
	$\tilde{X}_6$	50	60	T	ϕ	$\psi-\psi_A, \phi_{Max}$							
					T	$\psi-\psi_A$							
IV. Downwind	$\tilde{X}_7$	925	1075	h									
	SB	150	200	AS									
	GD	120	150	AS									
	Flaps	120	135	AS									
	$\tilde{X}_7$	120	200	AS									
	$\tilde{X}_7$	ψ_3-3	ψ_3+3	ψ									
	X_7	-5	$+5$	ϕ									
V. Final Turn(1)	X_8	118	125	AS	ϕ	ϕ_c				X_8	118	125	AS
	X_8	0	45	$\lvert\phi_{Max}\rvert$	h	h							
	$\tilde{X}_8$	25	35	$\lvert\phi\rvert$									
	X_9	108	112	AS									
	$\tilde{X}_9$	650	700	h									
	$\tilde{X}_8$	-15	-7.5	$\dot{h}$									
(End Final Turn)	X_{10}	250	350	h	T	$h, \psi-\psi_A$							
	X_{10}	ψ_A-2	ψ_A+2	ψ									

Table 10 (Continued)

Segment	EE X	EE V_{T1}	EE V_{T2}	EE V	EM X	EM Y	EO K	EO X	EO Y	EV X	EV V_{T1}	EV V_{T2}	EV V
VI. Final Approach[2]	$\tilde{X}_{10}$	ψ_A-2	ψ_A+2	ψ	h	h							
	$\tilde{X}_{10}$	−16	−8	$\dot{h}$	AS	AS							
	$\tilde{X}_{10}$	100	102	AS	$\delta_{F\text{-}Long}$	θ,h,P,AS							
	$\tilde{X}_{10}$	50	75	T	$\delta_{F\text{-}Lat}$	$\phi,q,\psi-\psi_A$							
					δ_{P-Lat}	$\phi,q,\psi-\psi_A$							
					δ_{P-Long}	θ,h,P,AS							
VII. Roundout	$\tilde{X}_{11}$	75	80	AS	$\dot{h}$	h,θ,AS							
	$\tilde{X}_{11}$	−7.5	0	$\dot{h}$									
	$\tilde{X}_{11}$	ψ_A-1	ψ_A+1	ψ									
	$\tilde{X}_{11}$	−2	+2	ϕ									
	$\tilde{X}_{11}$	Idle	Idle	T_{Min}									
VIII. Touchdown[3]	$\tilde{X}_{12}$	ψ_A-1	ψ_A+1	ψ	P	θ,h,AS							
	$\tilde{X}_{12}$	−2	+2	ϕ									
	$\tilde{X}_{12}$	0	5	θ									

(1), (2) Also includes E_D (h, ϕ, θ, AS, ψ; h, ϕ, θ, AS, $\psi-\psi_A$).

(3) Also includes ES (MAX θ, θ) and ES (MAX G, G).

Table 11. Special Terms Used in Segment Measures Specification for Approach and Landing

Term	Definition
X_1	Tape Mark
X_2	$\psi_o \geqslant \psi_A$
X_3	$\lvert\phi\rvert > 10^\circ$
X_4	$\lvert\phi\rvert = 5^\circ$
X_5	$\lvert\phi\rvert = 15^\circ$
X_6	$\lvert\psi_A - \psi\rvert = 90^\circ$
X_7	$\lvert\phi\rvert < 5^\circ$
X_8	$\lvert\phi\rvert = 10^\circ$
X_9	$\lvert\psi_A - \psi\rvert = 90^\circ$
X_{10}	$\lvert\phi\rvert = 5$
X_{11}	$T = 45$
X_{12}	$h = 0$
h	$h - h_{field}$
h_1	$h_{field} + 1000$
ψ_1	$\psi_A + 45$
ψ_2	$\psi_A - 45$
ψ_3	$\psi_A + 180$
h_o	$h(t_{X_1})$
ψ_o	$\psi(t_{X_1})$

Table 12. Segment and Maneuver Summary Measures for Approach and Landing

Segment	Summary Measure
I. Entry	PK(EE, EV, $E\sigma$)
	PMAX (EE, EV, $E\sigma$)
(45° Turn)	PK (EE, EM)
	PMAX (EE, EM)
II. Initial	PK (EE, EV)
	PMAX (EE, EV)
III. Pitch Out	PK (EE, EM)
	PMAX (EE, EM)
IV. Downwind	PK (EE)
	PMAX (EE)
V. Final Turn	PK (EE, EV, EM, E_D)
	PMAX (EE, EV, EM, E_D)
(End Final Turn)	PK (EE, EM)
	PMAX (EE, EM)
VI. Final Approach	PK (EE, EM, E_D)
	PMAX (EE, EM, E_D)
VII. Roundout	PK (EE, EM)
	PMAX (EE, EM)
VIII. Touchdown	PK (EE, EM, ES)
	PMAX (EE, EM, ES)
Total Maneuver	PK (PK)
	PMAX (PK)
	PMAX (PMAX)

Table 13. **Candidate Segment Measures for Barrel Roll**

Segment	EE				EM			EO		EV			
	X	V_{T1}	V_{T2}	V	X	Y	K	X	Y	X	V_{T1}	V_{T2}	V
I. Initial	X_1	5000	10000	h									
	X_1	87	93	T									
II. Entry	X_2	200	230	AS						X_2	0	0	θ
III. Quadrants	$\widetilde{X}_3$	−30	+30	q	θ	$\phi,\theta_{Max},\Delta h,AS$	2	θ	$\phi,\theta_{Max},\Delta h,AS$				
to VI. 1, 2, 3, & 4	$\widetilde{X}_3$	0	G_1	G	G	$\phi,\theta_{Max},\Delta h,AS$							
					q	$\phi,\theta_{Max},\Delta h,AS$							
					A_y	$\phi,\theta_{Max},\Delta h,AS$							
					$\delta_{F\text{-}Lat}$	$\phi,\theta_{Max},\Delta h,AS$							
					AS	$\phi,\theta_{Max},\Delta h$							
IV. Quadrant 2										X_4	$\theta_{Max}-2$	$\theta_{Max}+2$	θ
										X_4	$\lvert\psi_{Off}\rvert-3$	$\lvert\psi_{Off}\rvert+3$	ψ
V. Quadrant 3										X_4	ψ_o-3	ψ_o+3	ψ
										$\widetilde{X}_5$	$AS_{Min}-5$	$AS_{Min}+5$	AS
										$\widetilde{X}_5$	$h_{Max}-25$	$h_{Max}+25$	h
										$\widetilde{X}_5$	$\lvert\psi_{Off}\rvert-3$	$\lvert\psi_{Off}\rvert+3$	ψ
										X_5	−2	+2	θ
VI. Quadrant 4										X_6	$\theta_{Max}-2$	$\theta_{Max}+2$	θ
										X_6	$\lvert\psi_{Off}\rvert-3$	$\lvert\psi_{Off}\rvert+3$	ϕ
										X_6	ψ_o-3	ψ_o+3	ϕ
(End)	X_7	200	230	AS						X_7	h_o-25	h_o+25	h
										X_7	$\psi_{Off}-3$	$\psi_{Off}+3$	$\psi-\psi_o$

Table 14. Special Terms Used in Segment Measures Specification for Barrel Roll

Term	Definition
X_1	$\theta = \theta_L - 4$
X_2	$(\lvert\phi\rvert = 5) \cap (\phi = 0)$
X_3	$(\lvert\phi\rvert = 5) \cap X_2$
X_4	$\lvert\phi\rvert = 90$
X_5	$\phi = 180$
X_6	$\lvert\phi\rvert = 90$
X_7	$\phi = 0$
ψ_o	$\psi(T_{X_1})$
h_o	$h\,(T_{X_1})$
ψ_{off}	$\psi(T_{X_2}) - \psi_o$
G_1	Upper Limit on G's (to be determined)

Table 15. Segment and Maneuver Summary Measures for Barrel Roll

Segment	Summary Measure
I. Initial	PK (EE)
II. Entry	PK (EE, EV)
III-VI. Quadrants 1, 2, 3, and 4	PK (EM, Eσ) PMAX (EM, Eσ) P_d (EM)
III. Quadrant 1	PK (EE)
IV. Quadrant 2	PK (EV)
V. Quadrant 3	PK (EV)
VI. Quadrant 4	PK (EE, EV)
Total Maneuver	PK (PK) PK (PMAX) PK (P_d)

Table 16. **Candidate Segment Measures for Cloverleaf**

Segment	EE X	EE V_{T1}	EE V_{T2}	EE V	EM X	EM Y	EO K	EO X	EO Y	EV X	EV V_{T1}	EV V_{T2}	EV V
I. Initial	X_1	5000	10000	h									
	X_1	87	93	T									
	X_1	210	220	AS									
	$\tilde{X}_1$	-2	$+2$	ϕ									
	$\tilde{X}_1$	h_o-75	h_o+75	h									
	$\tilde{X}_1$	AS_o-5	AS_o+5	AS									
	$\tilde{X}_1$	ψ_o-3	ψ_o+3	ψ									
II. Pitch Up	$\tilde{X}_2$	1.5	2.5	G	G	θ	2	G	θ				
	$\tilde{X}_2$	-2	$+2$	ϕ	P	θ	2	P	θ				
	$\tilde{X}_2$	$\psi_{Io}-3$	$\psi_{Io}+3$	ψ	AS	θ	2	AS	θ				
III. Turn	$\tilde{X}_3$	1.5	3.5	G	θ	ϕ	2	G	ϕ	$\tilde{X}_3$	1.5	3.5	G
					$\psi-\psi_{Io}$	ϕ							
					G	ϕ							
					A_y	ϕ							
					AS	ϕ							
					q	ϕ							
IV. Pull Through:	$\phi=180$	-2	$+2$	θ	AS	θ	2	P	θ	$\phi=180$	-2	$+2$	θ
To 90°	X_4	178	182	ϕ	P	θ	2	G	θ	X_4	178	182	ϕ
	X_4	-2	$+2$	θ	G	θ	1	$\delta_{F\text{-}Long}$	θ	X_4	-2	$+2$	θ
	X_5	ψ_2-2	ψ_2+2	ψ	$\delta_{F\text{-}Long}$	θ				X_5	ψ_2-3	ψ_2+3	ψ
	X_6	ψ_3-2	ψ_3+2	ψ						X_6	ψ_3-2	ψ_3+2	ψ
	X_5+X_6	1.5	3.5	G						X_5+X_6	1.5	3.5	G
to 0°					AS'	θ	2	P	θ				
					P'	θ	2	G	θ				
					G	θ	1	$\delta_{F\text{-}Long}$	θ				
					$\delta_{F\text{-}Long}$	θ							
(End Pull Through)	X_7	210	220	AS						X_7	210	220	AS
										X_7	h_o	h_o	h

Table 17. **Special Terms Used in Segment Measures Specification for Cloverleaf**

Term	Definition
X_1	$\theta = 0$
X_2	$\theta = 5$
X_3	$(\theta > 40) \cap (\lvert\phi\rvert > 5)$
X_4	$h = h_{Max}$
X_5	$t < t\theta_{Min}$
X_6	$t \geq t\theta_{Min}$
ψ_o	$\psi(t_{X_1})$
AS_o	$AS(t_{X_1})$
h_o	$h(t_{X_1})$
ψ_{Io}	ψ_o
ψ_2	$\psi_{Io}+90(SGN[\psi(t_{X_4})-\psi_{Io}])$
ψ_3	ψ_2+180

Table 18. **Segment and Maneuver Summary Measures for Cloverleaf**

Segment	Summary Measure
I. Initial	PK (EE)
	PMAX (EE)
II. Pitch Up	PK (EE, EM, $E\sigma$)
	PMAX (EE, EM, $E\sigma$)
	P_d (EM)
III. Turn	PK (EM, $E\sigma$, EE, EV)
	PMAX (EM, $E\sigma$, EE, EV)
	P_d (EM)
IV. Pull Through	PK (EE, EV, EM, $E\sigma$)
	PMAX (EE, EV, EM, $E\sigma$)
	P_d (EM)
(End Pull Through)	PK (EE, EV)
	PMAX (EE, EV)
Total Maneuver	PK (PK)
	PMAX (PMAX)
	Pd (Pd)

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Table 19. **Candidate Segment Measures for Lazy 8**

Segment	EE X	EE V_{T1}	EE V_{T2}	EE V	EM X	EM Y	ES Y	ES X	EV X	EV V_{T1}	EV V_{T2}	EV V
I. Initial	X_1	h_1	h_2	h_o								
II. Quadrants to IX. 1 – 8					θ	$\phi, \theta_{Max}, \phi_{Max}, \Delta\psi$						
					AS	$\phi, \theta_{Max}, \phi_{Max}, \Delta\psi$						
					h	$\phi, \theta_{Max}, \phi_{Max}, \Delta\psi$						
					G	$\phi, \theta_{Max}, \phi_{Max}, \Delta\psi$						
					P	$\phi, \theta_{Max}, \phi_{Max}, \Delta\psi$						
					q	$\phi, \theta_{Max}, \phi_{Max}, \Delta\psi$						
					ϕ	$\phi_o, \theta, \Delta\psi$						
II. Quadrant 1	X_2	87	93	T			θ_{Max}	θ				
	X_2	200	230	AS								
III. Quadrant 2	X_3	40	50	$\|\phi\|$			θ_{Min}	θ/θ_{Max}				
	X_3	AS_o-70	AS_o-60	AS			θ_{Min}	ϕ				
	θ_M	40	50	$\|\psi-\psi_o\|$								
IV. Quadrant 3	X_4	−4	+4	θ					X_4	80	90	$\|\phi\|$
	X_4	80	90	$\|\phi\|$								
	X_4	AS_o-105	AS_o-95	AS								
V. Quadrant 4	θ_{Min}	125	145	$\|\psi-\psi_b\|$								
	X_5	AS_o-40	AS_o-30	AS								
	X_5	40	50	$\|\phi\|$								
VI. Quadrant to IX. 5 – 8					θ	$\phi, \theta_{Max}, \phi_{Max}$						
					AS	$\phi, \theta_{Max}, \phi_{Max}$						
					h	$\phi, \theta_{Max}, \phi_{Max}$						
					G	$\phi, \theta_{Max}, \phi_{Max}$						
					P	$\phi, \theta_{Max}, \phi_{Max}$						
					q	$\phi, \theta_{Max}, \phi_{Max}$						
					ϕ	$\phi_c, \theta, \Delta\psi'$						

Table 19 *(Continued)*

Segment	EE				EM		ES		EV			
	X	V_{T1}	V_{T2}	V	X	Y	Y	X	X	V_{T1}	V_{T2}	V
VI. Quadrant 5	X_6	ψ_o+177	ψ_o+183	ψ								
	X_6	AS_o-4	AS_o+4	AS								
	X_6	h_o+h_1-75	h_o+h_1+75	h								
VII. Quadrant 6	X_7	40	50	$\|\phi\|$								
	X_7	AS_o-70	AS_o-60	AS								
	θ_{Max}	40	50	$\|\psi-\psi_o\|$								
VIII. Quadrant 7	X_8	-4	$+4$	θ								
	X_8	80	90	$\|\phi\|$								
	X_8	AS_o-105	AS_o-95	AS								
IX. Quadrant 8	θ_{Min}	125	145	$\|\psi-\psi'_o\|$								
	X_9	AS_o-40	AS_o-30	AS								
	X_9	40	50	$\|\phi\|$								
(End)	X_{10}	ψ_o+177	ψ_o+183	ψ					X_{10}	-2	$+2$	θ
	X_{10}	AS_o-4	AS_o+4	AS								
	X_{10}	h_1+h_o-75	h_1+h_o+75	h								

Table 20. **Special Terms Used in Segment Measures Specification for Lazy 8**

Term	Definition
X_1	Tape Mark
X_2	$\theta = 10$
X_3	$\lvert\psi - \psi_o\rvert = 45$
X_4	$\lvert\psi - \psi_o\rvert = 90$
X_5	$\lvert\psi - \psi_o\rvert = 135$
X_6	$\phi = 0$
X_7	$\lvert\psi - \psi_o'\rvert = 45$
X_8	$\lvert\psi - \psi_o'\rvert = 90$
X_9	$\lvert\psi - \psi_o'\rvert = 135$
X_{10}	$\phi = 0$
h_o	h (tape mark)
AS_o	$AS(T_{X_2})$
ψ_o	$\psi\,(T_{X_2})$
$\Delta\psi$	$\psi - \psi_o$
ψ_o'	$\psi\,(T_{X_2}) + 180$
$\Delta\psi'$	$\psi - \psi_o'$

Table 21. **Segment and Maneuver Summary Measures for Lazy 8**

Segment	Summary Measure
I. Initial	EE
II. Quadrant 1	PK (EE, EM, ES) PMAX (EE, EM, ES)
III. Quadrant 2	PK (EE, EM, ES) PMAX (EE, EM, ES)
IV. Quadrant 3	PK (EE, EM, EV) PMAX (EE, EM, EV)
V. Quadrant 4	PK (EE, EM) PMAX (EE, EM)
VI. Quadrant 5	PK (EE, EM, EV, ES) PMAX (EE, EM, EV, ES)
VII. Quadrant 6	PK (EE, EM) PMAX (EE, EM)
VIII. Quadrant 7	PK (EE, EM) PMAX (EE, EM)
IX. Quadrant 8	PK (EE, EM) PMAX (EE, EM)
(End)	PK (EE, EV) PMAX (EE, EV)
Total Maneuver	PK (EE, PK) PMAX (EE, PK) PMAX (PMAX)

(5) Computes, for each maneuver segment, measures specified by the user of the following forms,

$E_M, E_\sigma, E_D, E_E, E_V, E_S$

(6) Computes, for each maneuver segment and each maneuver, summary measures of the forms P_K, P_d, P_{MAX}, P_p, $P_\rightarrow$, with weighting factors specified by the user as appropriate.

(7) Prints results of all maneuver segmentation, criterion functions, and measure computations.

(8) Performs validation tests[2] on computed candidate measures and prints results.

X. SUMMARY AND CONCLUDING REMARKS

The purpose of this study was to develop candidate T-37 pilot performance measures for 5 contact maneuvers and software techniques for computing and testing them using recorded flight data. The results of the study include a comprehensive set of candidate error measures developed on the basis of apparent content validity; several alternative methods of combining measures to form overall performance assessments as required; and a flexible software system for computing and testing for validity the measures herein developed (for the T-37) and any other user-specified measures of the general types incorporated.

The results also include a unique measurement-oriented method of operator task analysis and segmentation, and its application to five maneuvers taught in the Air Force UPT program. The method includes identification of two types of function segments (locus and sequence) within a given control task, wherein the set of dominant measurement variables is consistent. This identifies portions of each task in which the operator's primary control function involves consistent measurable variables, and suggests the types of measures (continuous and discrete) applicable to assessing the operator's control performance. The method also includes identification of task segments, wherein the relationship among dominant measurement variables is consistent. This identifies portions of each function segment in which the operator's primary control functions themselves remain consistent, and suggests the specific nature of the continuous or discrete measures applicable to performance assessment within the respective task segments.

Based on the application of this analysis technique to 5 UPT maneuvers, several types of measures were identified and defined algorithmically. Collectively, they support performance assessment in all maneuver segments. Then, specific measure formulae were derived for each segment. Finally, software was developed and implemented for computing user-specified measures and validation test results using recorded T-37 data.

The approach employed is one of two that have been identified for the general job of developing and testing candidate measures for operator performance tasks. In it, the researcher identifies the specific measures to be tested, assuring their content validity, and then the measures are computed and empirically tested for criterion-related validity. (The alternative approach (see Connelly et al., 1974) which was pursued concurrently involves computer generation of candidate measures from a broad spectrum of measure types, execution of criterion-related validation tests, and, lastly, researcher analysis of results and assurance of the content validity of derived measures.) The approach was applied successfully to develop candidate performance measures for 5 UPT maneuvers in a relatively systematic and thorough way.

This study was originally intended to extend through the validation phase of measurement development using T-37 student pilot performance data. Unfortunately, non-technical problems prevented the data collection, and the study had to be confined to developing candidate measures as reported herein. It is recognized that the work performed essentially amounts to developing the tools but never testing them. Content validity alone, however carefully assured, is not a substitute for empirically derived criterion-related validities.

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[2] These consist of three empirical validation tests designed and documented under a separate concurrent study (Connelly et al., 1974) and applied here as part of the overall software system. A brief description of the tests is provided in Appendix C.

Despite this kind of "stopping short," the study produced some novel concepts and techniques for analyzing performance tasks for measurement purposes, and a relatively flexible software system for use in continuing measurement research efforts. It also produced a comprehensive set of candidate measures of T-37 pilot performance, and a thorough analysis, specifically performed for measurement applications, of five representative UPT maneuvers. Hopefully, the work will, as a minimum, serve as a guideline for investigation of similar measurement problems, and inspire other efforts for pursuit through and including final validation and evaluation of results.

REFERENCES

Baum, D., Smith, J., & Goebel, R. *Selection and analysis of UPT maneuvers for automated proficiency measurement development.* AFHRL-TR-72-62, AD-767 580. Williams AFB, Ariz.: Flying Training Division, Air Force Human Resources Laboratory, July 1973.

Connelly, E., Bourne, F., Loental, D., & Knoop, P. *Computer-aided techniques for providing operator performance measures.* AFHRL-TR-74-87. Wright-Patterson AFB, OH: Advanced Systems Division, Air Force Human Resources Laboratory, 1974, in press.

Hoel, P.G. *Introduction to mathematical statistics.* New York: John Wiley and Sons, Inc., 1962.

Knoop, P.A., & Welde, W.L. *Automated pilot performance assessment in the T-37: A feasibility study.* AFHRL-TR-72-6, AD-766 446. Wright-Patterson AFB, OH: Advanced Systems Division, Air Force Human Resources Laboratory, April 1973.

Meister, D. *Human factors theory and practice.* John Wiley and Sons, Inc., 1971.

Miller, R.B. *Manual for man-machine job-task description.* American Institute for Research, Pittsburgh, Pennsylvania, 1955.

Morgan, G.T. *Human engineering guide for equipment design.* New York: McGraw-Hill, 1963.

Woodsen, & Conover. *Human engineering guide for equipment designers.* University of California Press, 1970.

BIBLIOGRAPHY

Training Manual ATCM 51-4. *Primary flying jet.* Hq Air Training Command, Randolph AFB, Texas.

Training Film FM-31. *T-37, barrel roll.* Hq Air Training Command, Randolph AFB, Texas.

Technical Order TO 1T-37B-1. *T-37 flight manual.* Hq Air Training Command, Randolph AFB, Texas.

Training Film FM-30. *T-37, lazy eights.* Hq Air Training Command, Randolph AFB, Texas.

Training Film FM-13. *T-37, normal overhead landing pattern (left turn).* Hq Air Training Command, Randolph AFB, Texas.

Training Film FM-14. *T-37, normal overhead landing pattern (left turn – real time).* Hq Air Training Command, Randolph AFB, Texas.

Training Film FM-15. *T-37, normal overhead landing pattern (right turn).* Hq Air Training Command, Randolph AFB, Texas.

Training Film FM-16. *T-37, normal overhead landing pattern (right turn – real time).* Hq Air Training Command, Randolph AFB, Texas.

Training Film FM-36. *T-37, split S.* Hq Air Training Command, Randolph AFB, Texas.

APPENDIX A: LEAST VARIANCE WEIGHTING OF LINEAR SUMS

Independent Measurements

Consider the case of approximating a continuum by a discrete selection of outputs. A single quantity, x, is measured by a variety of independent methods that yield unbiased results but each with a different accuracy.

Let the set of measures of x be x_i, i = 1, 2, ..., N and let the corresponding variances be σ_i^2 respectively. Some method of combining the x_1 into a single result is required. One method is to add the x_i together in a weighted fashion.

$$X_E = \sum_{i=1}^{N} w_i x_i \tag{1}$$

where the w_i are the weighting numbers and x_E is the expected value of x. The ensemble average of x_E is

$$\overline{x}_E = \overline{\sum_{i=1}^{N} w_i x_i} = \sum_{i=1}^{N} w_i \overline{x}_i = x_T \sum_{i=1}^{N} w_i \tag{2}$$

where $x_i = x_T$, the true value of x. Then, if the ensemble average of x_E is to equal the true value of x, it is necessary to constrain w_i such that,

$$\sum_{i=1}^{N} w_i = 1 \tag{3}$$

Since the variance is a measure of accuracy, and the "best" variance is desired, "best" can be defined to mean the smallest variance. We would like to choose the w_i to minimize σ^2, where

$$\sigma^2 = \overline{(x_E - \overline{x}_E)^2} \tag{4}$$

$$= \sum_{i=1}^{N} \sum_{j=1}^{N} w_i w_j \overline{(x_i - \overline{x}_i)(x_j - \overline{x}_j)} \tag{5}$$

If the x_i are independent,

$$\sigma^2 = \sum_{i=1}^{N} w_i^2 \sigma_i^2 \tag{6}$$

Now, the w_i must be chosen to minimize σ^2, while the sum of the w_i is constrained to equal unity.

An auxillary problem with no constraints is considered, such that if it is solved, then our original problem is solved. Consider the problem of choosing the w_i and λ that will minimize

$$S = \sum_{i=1}^{N} w_i^2 \sigma_i^2 + \lambda \left(\sum_{i=1}^{N} w_i - 1\right) \tag{7}$$

where λ is the Lagrangian multiplier. A necessary condition for the minimization of S is that each of its partial derivatives with respect to w_i and λ be equal to zero.

$$\frac{\partial S}{\partial \lambda} = \sum_{i=1}^{N} w_i - 1 = 0 \tag{8}$$

If this constraint is substituted into the equation for S, it can be seen that only σ^2 remains to be reduced. Thus, the solution of the auxillary problem without constraints is equivalent to the solution of the original problem.

$$\frac{\partial S}{\partial w_q} = 2\sum_{i=1}^{N} \sigma_i^2 w_i \left(\frac{\partial w_i}{\partial w_q}\right) + \lambda \sum_{j=1}^{N} \left(\frac{\partial w_j}{\partial w_q}\right) \tag{9}$$

where

$$\frac{\partial w_i}{\partial w_q} = \delta_{iq}$$

$$\frac{\partial S}{\partial w_q} = 0 = 2\sigma_q^2 w_q + \lambda \tag{10}$$

$$w_q = -\frac{\lambda}{2}\left(\frac{1}{\sigma_q^2}\right) \quad q = 1, 2, \ldots, N \tag{11}$$

Summing on q, setting the sum equal to 1, and solving for $\left(-\frac{\lambda}{2}\right)$

$$-\frac{\lambda}{2} = \frac{1}{\left(\sum_{q=1}^{N} \frac{1}{\sigma_q^2}\right)} \tag{12}$$

Then

$$w_q = \left(\frac{1}{\sigma_q^2}\right) \left(\frac{1}{\Sigma \left(\frac{1}{\sigma_j^2}\right)}\right) \tag{13}$$

Therefore the best estimate of x is:

$$x_E = \frac{1}{\Sigma (1/\sigma_q)^2} \sum_{i=1}^{N} \left(\frac{x_i}{\sigma_i^2}\right) \tag{14}$$

After combining equations (6) and (13), the variance is:

$$\sigma^2 = \frac{1}{\sum_{q=1}^{N} \frac{1}{(\sigma_q^2)}} \tag{15}$$

Dependent Variables

When measurements are not independent, the simplification from equation (5) to equation (6) cannot be made and,

$$\sigma^2 = \sum_{i=1}^{N} \sum_{j=1}^{N} w_i w_j v_{ij} \tag{16}$$

where the v_{ij} are the covariances:

$$v_{ij} = \overline{(x_i - \bar{x}_i)(x_j - \bar{x}_j)} \tag{17}$$

The new problem has the same constraint expressed in equation (3)

$$\sum_{i=1}^{N} w_i = 1 \tag{3}$$

and the w_i must be chosen to minimize σ^2. Similar to the above equation (7)

$$S = \sum_{i=1}^{N} \sum_{j=1}^{N} w_i w_j v_{ij} + \lambda \left[\sum_{i=1}^{N} w_i - 1 \right] \tag{18}$$

As above

$$\frac{\partial S}{\partial \lambda} = \sum_{i=1}^{N} (w_i - 1) = 0 \tag{19}$$

$$\frac{\partial S}{\partial w_q} = \sum_{j=1}^{N} w_j v_{qi} + \sum w_i v_{iq} + \lambda = 0 \tag{20}$$

since $v_{iq} = v_{qi}$, it is found that

$$\sum_{i=1}^{N} w_i v_{iq} = -\lambda/2 \qquad q = 1, 2, \ldots, N \tag{21}$$

Equations (21) are N linear equations with N unknowns. A solution for the w_i exists if the determinant of v_{ij} is not zero. Let the elements of the inverse matrix be c_{ij}. Then

$$\sum_{q=1}^{N} v_{iq} c_{qi} = \delta_{ij} \tag{22}$$

Multiply equation (21) by c_{qj} and sum on q

$$w_j = \left(-\frac{\lambda}{2}\right) \sum_{q=1}^{N} c_{qj} \tag{23}$$

Summing on j and solving for $(-\frac{\lambda}{2})$

$$\left(-\frac{\lambda}{2}\right) = \frac{1}{\left(\sum_{q=1}^{N}\sum_{j=1}^{N} c_{qj}\right)} \tag{24}$$

Therefore:

$$w_j = \frac{\left(\sum_{q=1}^{N} c_{qj}\right)}{\left(\sum_{q=1}^{N}\sum_{i=1}^{N} c_{qi}\right)} \tag{25}$$

Substituting into equation (16), the variance of the best estimate becomes:

$$\sigma^2 = \frac{1}{\left(\sum_{i=1}^{N}\sum_{q=1}^{N} c_{qi}\right)^2} \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{q=1}^{N}\sum_{s=1}^{N} d_{qj}c_{si}N_{ij} \tag{26}$$

Using equation (22)

$$\sigma^2 = \frac{1}{\left(\sum_{i=1}^{N}\sum_{q=1}^{N} c_{qi}\right)^2} \sum_{q=1}^{N}\sum_{s=1}^{N} c_{qs} \tag{27}$$

$$\sigma^2 = \frac{1}{\left(\sum_{i=1}^{N}\sum_{q=1}^{N} c_{qi}\right)} \tag{28}$$

Using matrix notation

$w_i \to w$

$v_{ij} \to V$

$c_{ij} \to V^{-1}$

let $u_i = 1, i = 1, 2, \ldots, N$ $\quad u_i \to u$

Equation (1) becomes $\sigma^2 = w^T V w$ (29)

Equation (3) becomes $u^T w = 1$ (30)

The problem is to choose w to minimize σ^2 while satisfying equation (30). Equation (18) becomes

$$S = w^T V w + \lambda \left[u^T w - 1 \right] \tag{31}$$

$$\frac{\partial S}{\partial \lambda} = u^T w - 1 = 0 \tag{32}$$

$$\delta S - 2w^T VS\delta w + \lambda u^T \ \delta w \tag{33}$$

where the first term in equation (33) results from the fact that a scalar is equal to its own transpose, and that $V = V^T$, therefore:

$$\delta S = \left[2w^T V \ + \ \lambda u^T \right] \ \delta w \tag{34}$$

$$\delta S = o \text{ for all } \delta w$$

$$w^T = (-\frac{\lambda}{2}) u^T V^{-1} \tag{35}$$

The transpose of equation (30) is taken and equation (35) is multiplied from the right by u, then solved for $(-\lambda/2)$

$$(-\lambda/2) = \frac{1}{u^T V^{-1} u} \tag{36}$$

and equation (35) becomes

$$w^T = \frac{u^T V^{-1}}{u^T V^{-1} u}$$

then

$$\sigma^2 = \frac{u^T V^{-1} V (V^{-1})^T u}{(u^T V^{-1} u)^2}$$

but $(V^{-1})^T = V^{-1}$, therefore:

$$\sigma^2 = \frac{1}{u^T V^{-1} u}$$

The correspondence with indexed notation is complete with

$$u^T V^{-1} u \quad \rightarrow \sum_{i=1}^{N} \sum_{q=1}^{N} c_{qi}$$

and

$$u^T V^{-1} \rightarrow \sum_{q=1}^{N} c_{qi}$$

APPENDIX B: MEASUREMENT OF TURN COORDINATION

Assume that the present turn provides a constant rate of rotation about a point distance r from the aircraft. Measurement of the rotation rate w can be provided by the rate of change of heading, thus,

$$w = \dot{\psi}$$

This turn rate provides an acceleration component assumed to be perpendicular to g (i.e., a level turn)

$$a = Vw = V\dot{\psi}$$

where V is aircraft velocity, which will be measured by airspeed (zero air velocity with respect to ground is assumed). Thus the proper roll angle for a coordinated turn is

$$\phi_C = \mathrm{TAN}^{-1}\left(\frac{V\dot{\psi}K}{g}\right)$$

This roll angle is to be used as a reference in measuring the degree of coordination of a turn.

APPENDIX C: VALIDATION TESTS[3]

For the vast majority of performance tasks, there is no single necessary and sufficient test that can be applied to candidate measures to assess their validity. Measures which appear to have content validity often fail to reliably discriminate even between novice and highly experienced performers. Measures which appear to have concurrent validity may or may not satisfy other validation criteria, depending on the reliability and sensitivity of the metric used as a basis of comparison.

The approach in this study was to develop three empirically-based validation tests to be applied by the measurement processor. Collectively, the tests are used to determine the likelihood that each candidate measure is valid. Final analysis and assurance of the measure's content validity is performed by the user of the processor, based on evidence accrued by it and printed out for his consideration.

The first test assesses the measure's potential contribution to discriminating between performances at opposite ends of the skill continuum. The data employed for this test are selected by the user. For the T-37 pilot performance tasks that were to have been addressed here, the following two types of data would have been investigated:

(1) Flights flown by instructor pilots to demonstrate their best performances and simulated novice performances of each maneuver.

(2) Flights flown by students at the neophyte stage and at the successful completion of training.

The techniques implemented to apply this first test include (a) comparison of residues from regression analyses; and (b) the rank sum statistic.

The second test assesses the measure's functional relationships with variables such as number of trials and time in training. A measure which demonstrates that learning has occurred from neophyte to experienced levels of performance would possess a higher likelihood of validity than one which consistently does not, for example. Again, the data to be employed for this test are specifiable by the user. For the T-37 pilot tasks, the following data would have been experimented with:

(1) Time in training

(2) Number of practice sorties on the maneuver

(3) Number of practice trials on the maneuver

The technique used to apply this test consists of developing and analyzing a multi-variable regression function. (An alternative technqiue based on the use of Markov learning models was conceived, but due to lack of data, has not yet been developed to the point of implementation.)

The third test assesses the measure's functional relationships with subjectively derived ordinal scale measures of performance. Measures which tend to reinforce the subjective ordering of performances are considered more likely to be valid than those which consistently fail to do so. The data employed for this test, as with the other tests, are specified by the user. For the T-37 tasks, instructor pilot ratings would have been investigated for use. The technique for applying the test is to develop and analyze multi-variable regression functions, as in the second test described in the preceding paragraph.

[3] Quoted directly from Connelly et al., (1974).